PB84-237320

VOC Emissions from Volatile Organic Liquid Storage Tanks - Background Information for Proposed Standards

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Jul 84

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/3-81-003a	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE VOC Emissions from Volatile Organic Liquid Storage Tanks - Background Information for Proposed Standards		5. REPORT DATE July 1984
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Air Quality Planning and Standards Environmental Protection Agency Research Triangle Park, North Carolina 27711		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-3063
12. SPONSORING AGENCY NAME AND ADDRESS DAA for Air Quality Planning and Standards Office of Air, Noise, and Radiation U.S. Environmental Protection Agency Research Triangle Park, North Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED Draft
		14. SPONSORING AGENCY CODE EPA/200/04

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Standards of Performance for the control of VOC emissions from Volatile Organic Liquid (VOL) storage tanks are being proposed under the authority of Section 111 of the Clean Air Act. These standards would apply to all new and existing storage tanks having a capacity of 75 cubic meters or larger, which are to be used for the storage of VOL. This document contains background information and environmental and economic impact assessments of the regulatory alternatives considered in developing the proposed standards.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air pollution	Equipment standard	Air Pollution Control	13 B
Pollution control	Standards of Performance		
Storage tanks			
Contact floating roofs			
Chemical manufacturing plants			
Volatile Organic Compounds			
Volatile Organic Liquids			
Bulk Liquid Terminals			

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 252
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/3-81-003a
July 1984

PB84-237320

Air

EPA

VOC Emissions from Volatile Organic Liquid Storage Tanks — Background Information for Proposed Standards

Draft EIS

NSPS

ODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA-450/3-81-003a

VOC Emissions from Volatile Organic Liquid Storage Tanks — Background Information for Proposed Standards

Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

July 1984

This report has been reviewed by the Emission Standards and Engineering Division of the Office of Air Quality Planning and Standards, EPA, and approved for publication. Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use. Copies of this report are available through the Library Services Office (MD-35), U. S. Environmental Protection Agency, Research Triangle Park, N. C. 27711, or from National Technical Information Services, 5285 Port Royal Road, Springfield, Virginia 22161.

ENVIRONMENTAL PROTECTION AGENCY

Background Information and Draft Environmental Impact Statement for Volatile Organic Liquid Storage Vessels

Prepared by:

Jack R Farmer 7/26/84

Jack R. Farmer Date
Director, Emission Standards and Engineering Division
U. S. Environmental Protection Agency (MD-13)
Research Triangle Park, North Carolina 27711

1. The proposed standards of performance would limit emissions of volatile organic compounds from new, modified, and reconstructed volatile organic liquid storage vessels. Section 111 of the Clean Air Act (42 U.S.C. 7411), as amended, directs the Administrator to establish standards of performance for any category of new stationary source of air pollution that ". . . causes or contributes significantly to air pollution which may reasonably be anticipated to endanger public health or welfare." It is anticipated that areas with high concentrations of petrochemical plants, such as the Gulf Coast and the West Coast, would be particularly affected.

2. Copies of this document have been sent to the following Federal Departments: Labor, Health and Human Services, Defense, Transportation, Agriculture, Commerce, Interior, and Energy; the National Science Foundation; the Council on Environmental Quality; State and Territorial Air Pollution Program Administrators; EPA Regional Administrators; Local Air Pollution Control Officials; Office of Management and Budget; and other interested parties.

3. The comment period for review of this document is 75 days from the date of publication of the proposed standard in the Federal Register. Mr. Doug Bell may be contacted at (919) 541-5578 regarding the date of the comment period.

4. For additional information contact:

Mr. James Durham
Emission Standards and Engineering Division (MD-13)
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711
Telephone: (919) 541-5671

5. Copies of this document may be obtained from:

U. S. Environmental Protection Agency Library (MD-35)
Research Triangle Park, North Carolina 27711
Telephone: (919) 541-2777

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

TABLE OF CONTENTS

Section Page

1 SUMMARY 1-1
1.1 Regulatory Alternatives 1-1
1.2 Environmental Impact. 1-2
1.3 Economic Impacts. 1-2

2 INTRODUCTION
2.1 Background and Authority for Standards. 2-1
2.2 Selection of Categories of Stationary Sources . . . 2-4
2.3 Procedure for Development of Standards of Performance 2-6
2.4 Consideration of Costs. 2-8
2.5 Consideration of Environmental Impacts. 2-9
2.6 Impact on Existing Sources. 2-10
2.7 Revision of Standards of Performance. 2-11

3 VOLATILE ORGANIC LIQUID STORAGE. 3-1
3.1 The Volatile Organic Liquid Storage Industry. . . . 3-1
3.2 Storage Tanks 3-3
3.3 Baseline Control and Emissions Estimates. 3-34
3.4 References. 3-39

4 CONTROL TECHNIQUES 4-1
4.1 Overview. 4-1
4.2 Fixed Roof Tanks. 4-7
4.3 Internal Floating Roof Tanks. 4-9
4.4 External Floating Roof Tanks. 4-17
4.5 Vapor Control or Recovery Systems on Fixed Roof Tanks 4-20
4.6 References. 4-25

5 MODIFICATION AND RECONSTRUCTION. 5-1
5.1 Provisions for Modifications and Reconstruction . . 5-1
5.2 Applicability to Volatile Organic Liquid Storage. . 5-3

(continued)

TABLE OF CONTENTS (Concluded)

Section		Page
6	REGULATORY ALTERNATIVES AND MODEL PLANTS	6-1
	6.1 Regulatory Alternatives	6-1
	6.2 Model Plants	6-4
7	ENVIRONMENTAL IMPACTS	7-1
	7.1 Introduction	7-1
	7.2 Air Pollution Impacts	7-1
	7.3 Water Quality and Solid Waste Impacts	7-5
	7.4 Energy Impact	7-6
	7.5 Other Environmental Concerns	7-6
	7.6 References	7-7
8	COST ANALYSIS	8-1
	8.1 Capital Costs	8-2
	8.2 Annualized Capital Costs	8-18
	8.3 Annualized Costs	8-20
	8.4 Cost Effectiveness	8-20
	8.5 Cost of Other Federal Regulations	8-21
	8.6 Costs and Cost Effectiveness of Controls on an Individual Tank	8-27
	8.7 References	8-34
9	ECONOMIC IMPACT	9-1
	9.1 Industry Profile	9-1
	9.2 Economic Impacts of Regulatory Alternatives	9-31
	9.3 Regulatory, Inflationary, Socioeconimic, and Small-Business Impact	9-50
	9.4 References	9-52
APPENDICES		
	A	A-1
	B	B-1
	C	C-1
	D	D-1

LIST OF FIGURES

Figure Page

3-1 Typical fixed roof tank 3-5

3-2 External floating roof tank 3-7

3-3 Internal floating roof tanks. 3-8

3-4 Primary seals 3-11

3-5 Rim-mounted secondary seals on external floating roofs 3-13

3-6 Metallic shoe seal with shoe-mounted secondary seal . . 3-14

3-7 Typical flotation devices and perimeter seals for internal floating roofs 3-16

3-8 Rim mounting of a secondary seal on internal floating roof. 3-18

3-9 Typical internal floating roof tank cross section . . . 3-20

3-10 Internal floating roof deck fittings. 3-21

3-11 Baseline control summary. 3-36

3-12 Baseline emissions totals (Mg/yr: 1977 tank population) and numbers of tanks by vapor pressure/tank size region. 3-38

4-1 Emissions rates for alternative equipment types (50 turnovers per year) 4-5

4-2 Emissions rates for alternative equipment types (10 turnovers per year) 4-6

4-3 Carbon adsorption unit using steam regeneration 4-22

4-4 Thermal oxidation unit. 4-24

9-1 Organic chemical industry flow chart 9-2

9-2 VOL storage tank market for tanks in volume interval as characterized in the economic impact analysis . . . 9-33

C-1 Process and instrumentation schematic C-1

C-2 Plan view of noncontact bolted IFR C-4

C-3 Elevation view of noncontact bolted IFR in test tank C-5

C-4 Plan view of contact welded IFR C-6

C-5 Elevation view of contact welded IFR in test tank . . . C-7

C-6 Plan view of contact bolted IFR C-8

C-7 Elevation view of contact bolted IFR in test tank . . . C-9

C-8 Example of fitting emission bench test apparatus . . . C-18

LIST OF TABLES

Table		Page
1-1	Assessment of Environmental, Energy, and Economic Impacts for Each Regulatory Alternative Considered for New VOL Storage Vessels	1-3
3-1	National Industrial VOL Tank Distribution According to Vapor Pressure (1977)	3-2
3-2	National Industrial VOL Tank Distribution According to Tank Size (1977)	3-2
3-3	Statistics for the National Tank Population in VOL Terminal Storage (1979)	3-4
3-4	Seal Related Factors for External Floating Roof Tanks	3-28
3-5	Typical Number of Columns as a Function of Tank Diameters	3-32
3-6	Summary of Deck Fitting Loss Factors (K_f) and Typical Number of Fittings (N_f)	3-33
4-1	Hierarchy of Equipment Types Based on Emissions Rate	4-3
4-2	Model Tank Emission Rates for Different Equipment Options	4-8
4-3	Effectiveness of Internal and External Floating Roof Tanks Compared to a Fixed Roof Tank for the Model Tank	4-11
4-4	"Controlled" and "Uncontrolled" Internal Floating Roof Deck Fittings	4-12
4-5	Internal Floating Roof Rim Seal Systems Seal Loss Factors and Control Efficiencies	4-14
4-6	External Floating Roof Tank Seal System Control Efficiencies	4-19
6-1	Model Terminal	6-6
6-2	Model Producer/Consumer	6-6
7-1	Fifth-Year Emissions Resulting from the Regulatory Alternatives	7-3
7-2	Fifth-Year Emissions Reductions Resulting from the Regulatory Alternatives	7-4
8-1	Estimated Installed Capital Cost of a Fixed Roof Tank	8-3

(continued)

LIST OF TABLES (Continued)

Table		Page
8-2	Estimated Installed Capital Cost of a Noncontact Internal Floating Roof	8-4
8-3	Estimated Installed Cost of a Welded Contact Internal Floating Roof with Secondary Seals	8-5
8-4	Estimated Installed Capital Cost of External Floating Roof Tanks with Secondary Seals.	8-6
8-5	Cost of Regulatory Alternative I	8-9
8-6	Cost of Regulatory Alternative II.	8-10
8-7	Cost of Regulatory Alternative III	8-11
8-8	Cost of Regulatory Alternative IV.	8-12
8-9	Cost of Regulatory Alternative V	8-13
8-10	Cost of External Floating Roof Tanks with Primary Seal and Secondary Seal	8-14
8-11	Cost of External Floating Roof Tanks with Liquid-Mounted Primary Seal and Secondary Seal.	8-15
8-12	Cost of Vapor Control by Incineration Techniques	8-16
8-13	Cost of Vapor Recovery by Carbon Adsorption Techniques	8-17
8-14	Lifetimes of Control Equipment	8-19
8-15	Cost Annualizing Assumptions	8-19
8-16	Federal Laws Regulating Toxic Chemicals.	8-22
8-17	Statutes That May be Applicable to the Manufacture and Storage of Volatile Organic Liquids.	8-23
8-18	Proposed Regulations That Will Affect the Chemical Manufacturing Industry	8-26
8-19	Capital and Annualized Costs for Baseline and Control Equipment for the Model VOL Tank	8-28
8-20	Absolute Cost Effectiveness of Controlling Fixed Roof Tank Emissions from the Model Tank	8-29
8-21	Incremental Cost Effectiveness between Internal Floating Roof Seal Types in the Model Tank	8-30
8-22	Incremental Cost Effectiveness of Controlling Deck Seam Emissions in the Model Tank	8-31
8-23	Regulatory Alternatives and Incremental Cost Effectiveness ($/Mg) between Regulatory Alternatives in the Model Tank	8-32

(continued)

LIST OF TABLES (Continued)

Table		Page
8-24	Incremental Cost Effectiveness between Equipment Specified by Each Regulatory Alternative and an External Floating Roof Tank with a Mechanical Shoe Seal and a Secondary Seal	8-33
9-1	Resource Use by Producers of Industrial Organic Chemicals (SIC 286)	9-6
9-2	Resource Use by Producers of Plastics Materials and Synthetics (SIC 282)	9-7
9-3	Capital Expenditures and Operating Rates for SIC 286 and SIC 282, 1958-1978	9-8
9-4	Historical Production and Sales of Industrial Organic Chemicals, 1955-1981	9-10
9-5	Historical Production and Sales of Plastics and Resins Materials, 1955-1981	9-12
9-6	Export and Import Values of Industrial Organic Chemicals (SIC 286) Excluding Gum and Wood Chemicals (SIC 2861) for Selected Years Between 1972 and 1981	9-13
9-7	Export and Import Values of Plastics Materials and Synthetics (SIC 282) for Selected Years Between 1972 and 1981	9-13
9-8	Industry-wide Market Concentration Based on Capacity Share Data, 1976	9-17
9-9	Geographic Distribution of Establishments, Employees, and Value of Shipments of SIC 286, Industrial Organic Chemicals	9-18
9-10	Geographic Distribution of Establishments, Employees, and Value of Shipments of SIC 282, Plastics Materials and Synthetics	9-19
9-11	Total 1982 Merchant Liquid Bulk Capacity, by State	9-21
9-12	Historical Price Data for Industrial Organic Chemicals and Plastics, Resins Materials, and Elastomers, 1955-1981	9-23
9-13	Projection of VOL Storage Tank Construction--1984 to 1988 All Capacities, Vapor Pressures, and Roof Designs	9-28
9-14	Estimated Percentage Distribution of VOL Storage Tanks by Vapor Pressure and Tank Capacity, 1977	9-29
9-15	Projection of VOL Storage Tank Construction by Vapor Pressure and Tank Size, 1984-1988	9-30
9-16	Price Impacts of the Regulatory Alternatives for the Model Terminal and Model Producer/Consumer	9-37

(continued)

LIST OF TABLES (Continued)

Table Page

9-17 Percentage Change in Output Price for the Model Plants Due to the Regulatory Alternatives 9-38

9-18 Additional Investment Required by Each of the Regulatory Alternatives for the Model Independent Terminal and Model Producer/Consumer (10^3 $1982) 9-40

9-19 The New Tank Population Impacted by Regulatory Alternative I as a Percentage of the Projected New Tank Population. 9-42

9-20 The New Tank Population Impacted by Regulatory Alternatives II-V as a Percentage of the Projected New Tank Population. 9-43

9-21 Additional Nationwide Investment in VOL Storage Required by the Regulatory Alternatives, 1984-1988 9-47

9-22 Fifth-Year Nationwide Annualized Cost of the Regulatory Alternatives 9-49

C-1 Summary of Test Conditions for Phase 1 and 1R C-10

C-2 Summary of Test Conditions for Phase 2 and 2R (1) C-12

C-3 Summary of Test Conditions for Phase 3 and 3R (1) C-14

C-4 Summary of Test Results for All Potentially Relevant Tests C-15

C-5 Summary of IFR Deck Fitting Emission Tests C-19

C-6 Permeability of Polyurethane Coated Nylon Fabric C-20

C-7 Comparison of Wiper Seals to Foam-Filled Vapor-Mounted Seals C-22

C-8 Comparison of Liquid-Mounted Seal to Vapor-Mounted Seal . . C-23

C-9 Bolted Deck Seam Emissions[1] C-25

C-10 Comparison of Emissions as a Function of Liquid Type C-26

D-1 Assumptions Used for Projections of New Tank Construction D-4

D-2 Estimated Total Annual VOC Emissions From Petroleum Storage Tanks[a] Reference Year D-10

D-3 Estimated Total Annual VOC Emissions From Petroleum Storage Tanks[a] 1983 - Scenario A D-11

D-4 Estimated Total Annual VOC Emissions From Petroleum Storage Tanks[a] 1983 - Scenario B D-12

(continued)

LIST OF TABLES (Concluded)

Table		Page
D-5	Estimated Total Annual VOC Emissions From Petroleum Storage Tanks[a] 1988 - Scenario A	D-13
D-6	Estimated Total Annual VOC Emissions From Petroleum Storage Tanks[a] 1988 - Scenario B	D-14
D-7	Estimated Total Annual VOC Emissions From Petroleum Storage Tanks[a] 1988 - Scenario C	D-15
D-8	Estimated Total Annual VOC Emissions From Petroleum Storage Tanks[a] 1988 - Scenario D	D-16
D-9	Estimated Total Annual VOC Emissions From Petroleum Storage Tanks[a] 1988 - Scenario E	D-17
D-10	Estimated Total Annual VOC Emissions From Petroleum Storage Tanks[a] 1988 - Scenario F	D-18
D-11	Estimated Total Number of Petroleum Storage Tanks[a] Reference Year	D-19
D-12	Estimated Total Number of Petroleum Storage Tanks[a] 1983 Scenario A and B	D-20
D-13	Estimated Total Number of Petroleum Storage Tanks[a] 1983 Scenarios A, B, and E	D-21
D-14	Estimated Total Number of Petroleum Storage Tanks[a] 1983 Scenario C	D-22
D-15	Estimated Total Number of Petroleum Storage Tanks[a] 1983 Scenario D	D-23
D-16	Estimated Total Number of Petroleum Storage Tanks[a] 1983 Scenario F	D-24

1. SUMMARY

Standards of performance for new stationary sources are established under Section 111 of the Clean Air Act (42 U.S.C. 7411), as amended in 1977. Section 111 directs the Administrator to establish standards of performance for any category of new stationary source of air pollution which "causes or contributes significantly to, air pollution which may reasonably be anticipated to endanger public health or welfare." This background information document supports the proposed standards, which would control emissions of volatile organic compounds (VOCs) from vessels that store volatile organic liquids (VOLs). VOL storage vessels are primarily located at chemical manufacturing facilities and bulk storage terminals. These vessels are used for storing a variety of materials, including raw materials, final products, and/or usable byproducts, as well as waste tars, residues, and nonusable byproducts.

1.1 REGULATORY ALTERNATIVES

In order to evaluate the environmental, economic, and energy impacts associated with implementation of a standard for VOL storage vessels, the Administrator has examined the impacts of several regulatory alternatives for VOL storage vessels. The VOL regulatory alternatives, in order of increasing emission control potential, would require that each vessel storing a VOL be equipped with the control technology described as follows:

- Regulatory Alternative 0 - no additional control over baseline.
- Regulatory Alternative I - an internal floating roof with a vapor-mounted primary seal (IFR_{vm}).
- Regulatory Alternative II - an internal floating roof with a liquid-mounted primary seal (IFR_{lm}).

- Regulatory Alternative III - an internal floating roof with a liquid-mounted primary seal and controlled deck fittings ($IFR_{lm,cf}$).
- Regulatory Alternative IV - an internal floating roof with a liquid-mounted primary seal controlled deck fittings, and a continuous secondary seal ($IFR_{lm,cf,ss}$).
- Regulatory Alternative V - a welded internal floating roof with a liquid-mounted primary seal, controlled deck fittings and a continuous secondary seal (${}_{w}IFR_{lm,cf,ss}$).

1.2 ENVIRONMENTAL IMPACT

The environmental regulatory alternatives are summarized in Table 1-1. None of the alternatives has any adverse environmental impacts. The environmental impacts are discussed in detail in Chapter 7.

1.3 ECONOMIC IMPACTS

The economic impacts are also summarized in Table 1-1. None of the alternatives have any potential adverse economic impacts. The economic impacts are discussed in detail in Chapter 9.

Table 1-1. ASSESSMENT OF ENVIRONMENTAL, ENERGY, AND ECONOMIC IMPACTS FOR EACH REGULATORY ALTERNATIVE CONSIDERED FOR NEW VOL STORAGE VESSELS

Administrative alternative	Air impact	Water impact	Solid waste impact	Energy impact	Economic impact
Regulatory Alternative 0	-2**	0	0	0	0
Regulatory Alternative I	+1**	0	0	0	-1**
Regulatory Alternative II	+2**	0	0	0	-1**
Regulatory Alternative III	+3**	0	0	0	-1**
Regulatory Alternative IV	+3**	0	0	0	-1**
Regulatory Alternative V	+3**	0	0	0	-3**

[a]KEY:
+ Beneficial impact
- Adverse impact
0 No impact
1 Negligible impact
2 Small impact
3 Moderate impact
4 Large impact
5 Very large impact
* Short term impact
** Long term impact
*** Irreversible impact

2. INTRODUCTION

2.1 BACKGROUND AND AUTHORITY FOR STANDARDS

Before standards of performance are proposed as a Federal regulation, air pollution control methods available to the affected industry and the associated costs of installing and maintaining the control equipment are examined in detail. Various levels of control based on different technologies and degrees of efficiency are expressed as regulatory alternatives. Each of these alternatives is studied by EPA as a prospective basis for a standard. The alternatives are investigated in terms of their impacts on the economics and well-being of the industry, the impacts on the national economy, and the impacts on the environment. This document summarizes the information obtained through these studies so that interested persons will be able to see the information considered by EPA in the development of the proposed standard.

Standards of performance for new stationary sources are established under Section 111 of the Clean Air Act (42 U.S.C. 7411) as amended, hereinafter referred to as the Act. Section 111 directs the Administrator to establish standards of performance for any category of new stationary source of air pollution which "causes, or contributes significantly to, air pollution which may reasonably be anticipated to endanger the public health or welfare."

The Act requires that standards of performance for stationary sources reflect "the degree of emission reduction achievable which (taking into consideration the cost of achieving such emission reduction, and any nonair quality health and environmental impact and energy requirements) the Administrator determines has been adequately demonstrated for that category of sources." The standards apply only to stationary sources whose construction or modification commences after regulations are proposed by publication in the Federal Register.

The 1977 amendments to the Act altered or added numerous provisions that apply to the process of establishing standards of performance.

1. EPA is required to review the standards of performance every 4 years and, if appropriate, revise them.

2. EPA is authorized to promulgate a standard based on design, equipment, work practice, or operational procedures when a standard based on emission levels is not feasible.

3. The term "standards of performance" is redefined, and a new term "technological system of continuous emission reduction" is defined. The new definitions clarify that the control system must be continuous and may include a low-polluting or nonpolluting process or operation.

4. The time between the proposal and promulgation of a standard under Section 111 of the Act may be extended to 6 months.

Standards of performance, by themselves, do not guarantee protection of health or welfare because they are not designed to achieve any specific air quality levels. Rather, they are designed to reflect the degree of emission limitation achievable through application of the best adequately demonstrated technological system of continuous emission reduction, taking into consideration the cost of achieving such emission reduction, any nonair quality health and environmental impacts, and energy requirements.

Congress had several reasons for including these requirements. First, standards with a degree of uniformity are needed to avoid situations in which some States may attract industries by relaxing standards relative to other States. Second, stringent standards enhance the potential for long-term growth. Third, stringent standards may help achieve long-term cost savings by avoiding the need for more expensive retrofitting if pollution ceilings are reduced in the future. Fourth, certain types of standards for coal-burning sources can adversely affect the coal market by driving up the price of low-sulfur coal or effectively excluding certain coals from the reserve base because their untreated pollution potentials are high. Congress does not intend that new source performance standards contribute to these problems. Fifth, the standard-setting process should create incentives for improved technology.

Promulgation of standards of performance does not prevent State or local agencies from adopting more stringent emission limitations for the same sources. States are free under Section 116 of the Act to establish even more stringent emission limits than those established under Section 111 or those necessary to attain or maintain the National Ambient Air Quality Standards (NAAQS) under Section 110. Thus, new sources may in some cases be subject to limitations more stringent than standards of performance under Section 111, and prospective owners and operators of new sources should be aware of this possibility in planning for such facilities.

A similar situation may arise when a major emitting facility is to be constructed in a geographic area that falls under the provisions for prevention of significant deterioration of air quality in Part C of the Act. These provisions require, among other things, that major emitting facilities to be constructed in such areas be subject to best available control technology. The term "best available control technology" (BACT), as defined in the Act, means:

> an emission limitation based on the maximum degree of reduction of each pollutant subject to regulation under this Act emitted from, or which results from, any major emitting facility, which the permitting authority, on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs, determines is achievable for such facility through application of production processes and available methods, systems, and techniques, including fuel cleaning or treatment or innovative fuel combustion techniques for control of each such pollutant. In no event shall application of "best available control technology" result in emissions of any pollutants which will exceed the emissions allowed by any applicable standard established pursuant to Sections 111 or 112 of this Act. (Section 169(3)).

Although standards of performance are normally structured in terms of numerical emission limits where feasible, alternative approaches are sometimes necessary. In some cases, physical measurement of emissions from a new source may be impractical or exorbitantly expensive. Section 111(h) provides that the Administrator may promulgate a design or equipment standard in those cases in which it is not feasible to prescribe or enforce a standard of performance. For example, emissions of hydrocarbons from storage vessels for petroleum liquids are greatest during tank filling. The nature of the emissions (high concentrations for short periods during filling and low concentrations for longer periods during storage) and the configuration of storage tanks make direct emission measurement impractical. Therefore, a more practical approach to standards of performance for storage vessels has been equipment specification.

In addition, Section 111(j) authorizes the Administrator to grant waivers of compliance to permit a source to use innovative continuous emission control technology. To grant the waiver, the Administrator must find (1) a substantial likelihood that the technology will produce greater emission reductions than the standards require, or an equivalent reduction at lower economic, energy, or environmental cost, (2) the proposed system has not been adequately demonstrated, (3) the technology will not cause or contribute to an unreasonable risk to the public health, welfare, or safety, (4) the governor of the State where the source is located consents, and (5) the waiver will not prevent the attainment or maintenance of any ambient standard. A waiver may have conditions attached to ensure that the source will not prevent attainment of any NAAQS. Any such condition will have the force of a performance standard. Finally, waivers have definite end dates and may be terminated earlier if the conditions are not met or if the system fails to perform as expected. In such a case, the source may be given up to 3 years to meet the standards with a mandatory progress schedule.

2.2 SELECTION OF CATEGORIES OF STATIONARY SOURCES

Section 111 of the Act directs the Adminstrator to list categories of stationary sources. The Administrator "shall include a category of sources in such list if in his judgment it causes, or contributes significantly to, air pollution which may reasonably be anticipated to endanger public health or welfare." Proposal and promulgation of standards of performance are to follow.

Since passage of the Clean Air Amendments of 1970, considerable attention has been given to the development of a system for assigning priorities to various source categories. The approach specifies areas of interest by considering the broad strategy of the Agency for implementing the Clean Air Act. Often, these "areas" are actually pollutants emitted by stationary sources. Source categories that emit these pollutants are evaluated and ranked by a process involving such factors as (1) the level of emission control (if any) already required by State regulations, (2) estimated levels of control that might be required from standards of performance for the source category, (3) projections of growth and replacement of existing facilities for the source category, and (4) the estimated incremental amount of air pollution that could be prevented in a preselected future year by standards of performance for the source category. Sources for which new source performance standards were promulgated or were under development during 1977, or earlier, were selected on these criteria.

The Act amendments of August 1977 establish specific criteria to be used in determining priorities for all major source categories not yet listed by EPA. These are (1) the quantity of air pollutant emissions that each such category will emit or will be designed to emit, (2) the extent to which each such pollutant may reasonably be anticipated to endanger public health or welfare, and (3) the mobility and competitive nature of each such category of sources and the consequent need for nationally applicable new source standards of performance.

The Administrator is to promulgate standards for these categories according to the schedule referred to earlier.

In some cases, it may not be feasible to immediately develop a standard for a source category with a high priority. This situation might occur when a program of research is needed to develop control techniques, or because techniques for sampling and measuring emissions may require refinement. In developing standards, differences in the time required to complete the necessary investigation for different source categories must also be considered. For example, substantially more time may be necessary if numerous pollutants must be investigated from a single source category. Furthermore, even late in the development process, the schedule for completion of a standard may change. For example, inability to obtain emission data from well-controlled sources in time to pursue the development process systematically may force a change in scheduling. Nevertheless, priority ranking is, and will continue to be, used to establish the order in which projects are initiated and resources assigned.

After the source category has been chosen, the types of facilities within the source category to which the standard will apply must be determined. A source category may have several facilities that cause air pollution; emissions from these facilities may vary from insignificant to very expensive to control. Economic studies of the source category and of applicable control technology may show that air pollution control is better served by applying standards to the more severe pollution sources. For this reason, and because there is no adequately demonstrated system for controlling emissions from certain facilities, standards often do not apply to all facilities at a source. For the same reasons, the standards may not apply to all air pollutants emitted. Thus, although a source category may be selected to be covered by a standard of performance, all pollutants or facilities within that source category might not be covered by the standards.

2.3 PROCEDURE FOR DEVELOPMENT OF STANDARDS OF PERFORMANCE

Standards of performance must (1) realistically reflect best demonstrated control practice, (2) adequately consider the cost, the nonair-quality health and environmental impacts, and the energy requirements of such control, (3) be applicable to existing sources that are modified or reconstructed as well as to new installations, and (4) meet these conditions for all variations of operating conditions being considered anywhere in the country.

The objective of a program for developing standards is to identify the best technological system of continuous emission reduction that has been adequately demonstrated. The standard-setting process involves three principal phases of activity: (1) information gathering, (2) analysis of the information, and (3) development of the standard of performance.

During the information-gathering phase, industries are queried through a telephone survey, letters of inquiry, and plant visits by EPA representatives. Information is also gathered from many other sources, and a literature search is conducted. From the knowledge acquired about the industry, EPA selects certain plants at which emission tests are conducted to provide reliable data that characterize the pollutant emissions from well-controlled existing facilities.

In the second phase of a project, the information about the industry and the pollutants emitted is used in analytical studies. Hypothetical "model plants" are defined to provide a common basis for analysis. The model plant definitions, national pollutant emission data, and existing State regulations governing emissions from the source category are then used in establishing "regulatory alternatives." These regulatory alternatives are essentially different levels of emission control.

EPA conducts studies to determine the impact of each regulatory alternative on the economics of the industry and on the national economy, on the environment, and on energy consumption. From several possibly applicable alternatives, EPA selects the single most plausible regulatory alternative as the basis for a standard of performance for the source category under study.

In the third phase of a project, the selected regulatory alternative is translated into a standard of performance, which, in turn, is written in the form of a Federal regulation. The Federal regulation, when applied to newly constructed plants, will limit emissions to the levels indicated in the selected regulatory alternative.

As early as is practical in each standard-setting project, EPA representatives discuss the possibilities of a standard, and the form it might take with members of the National Air Pollution Control Techniques Advisory Committee. Industry representatives and other interested parties also participate in these meetings.

The information acquired in the project is summarized in the background information document (BID). The BID, the standard, and a preamble explaining the standard are widely circulated to the industry being considered for control, environmental groups, other government agencies, and offices within EPA. Through this extensive review process, the viewpoints of expert reviewers are considered as changes are made to the documentation.

A "proposal package" is assembled and sent through the offices of EPA Assistant Administrators for concurrence before the proposed standard is officially endorsed by the EPA Administrator. After being approved by the EPA Administrator, the preamble and the proposed regulation are published in the Federal Register.

As a part of the Federal Register announcement of the proposed regulation, the public is invited to participate in the standard-setting process. EPA invites written comments on the proposal and also holds a public hearing to discuss the proposed standard with interested parties. All public comments are summarized and incorporated into a second volume of the BID. All information reviewed and generated in studies in support of the standard of performance is available to the public in a "docket" on file in Washington, D.C.

Comments from the public are evaluated, and the standards of performance may be altered in response to the comments.

The significant comments and EPA's position on the issues raised are included in the "preamble" of a promulgation package, which also contains the draft of the final regulation. The regulation is then subjected to another round of review and refinement until it is approved by the EPA Administrator. After the Administrator signs the regulation, it is published as a "final rule" in the Federal Register.

2.4 CONSIDERATION OF COSTS

Section 317 of the Act requires an economic impact assessment with respect to any standard of performance established under Section 111 of the Act. The assessment is required to contain an analysis of (1) the costs of compliance with the regulation, including the extent to which the cost of compliance varies depending on the effective date of the regulation and the development of less expensive or more efficient methods of compliance, (2) the potential inflationary or recessionary effects of the regulation, (3) the effects the regulation might have on small business with respect to competition, (4) the effects of the regulation on consumer costs, and (5) the effects of the regulation on energy use. Section 317 also requires that the economic impact assessment be as extensive as practicable.

The economic impact of a proposed standard upon an industry is usually addressed both in absolute terms and in terms of the control costs that would be incurred as a result of compliance with typical, existing State control regulations. An incremental approach is necessary because both new and existing plants would be required to comply with

State regulations in the absence of a Federal standard of performance. This approach requires a detailed analysis of the economic impact from the cost differential that would exist between a proposed standard of performance and the typical State standard.

Air pollutant emissions may cause water pollution problems, and captured potential air pollutants may pose a solid waste disposal problem. The total environmental impact of an emission source must, therefore, be analyzed and the costs determined whenever possible.

A thorough study of the profitability and price-setting mechanisms of the industry is essential to the analysis so that an accurate estimate of potentially adverse economic impacts can be made for proposed standards. It is also essential to know the capital requirements for pollution control systems already placed on plants so that the additional capital requirements necessitated by these Federal standards can be placed in proper perspective. Finally, it is necessary to assess the availability of capital to provide the additional control equipment needed to meet the standards of performance.

2.5 CONSIDERATION OF ENVIRONMENTAL IMPACTS

Section 102(2)(C) of the National Environmental Policy Act (NEPA) of 1969 requires Federal agencies to prepare detailed environmental impact statements on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment. The objective of NEPA is to build into the decisionmaking process of Federal agencies a careful consideration of all environmental aspects of proposed actions.

In a number of legal challenges to standards of performance for various industries, the United States Court of Appeals for the District of Columbia Circuit has held that environmental impact statements need not be prepared by the Agency for proposed actions under Section 111 of the Clean Air Act. Essentially, the Court of Appeals has determined that the best system of emission reduction requires the Administrator to take into account counter-productive environmental effects of a proposed standard, as well as economic costs to the industry. On this basis, therefore, the Court established a narrow exemption from NEPA for EPA determination under Section 111.

In addition to these judicial determinations, the Energy Supply and Environmental Coordination Act (ESECA) of 1974 (PL-93-319) specifically exempted proposed actions under the Clean Air Act from NEPA requirements. According to Section 7(c)(1), "no action taken under the Clean Air Act shall be deemed a major Federal action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969." (15 U.S.C. 793(c)(1))

Nevertheless, the Agency has concluded that the preparation of environmental impact statements could have beneficial effects on certain regulatory actions. Consequently, although not legally required to do so by Section 102(2)(C) of NEPA, EPA has adopted a policy requiring that environmental impact statements be prepared for various regulatory actions, including standards of performance developed under Section 111 of the Act. This voluntary preparation of environmental impact statements, however, in no way legally subjects the Agency to NEPA requirements.

To implement this policy, a separate section in this document is devoted solely to an analysis of the potential environmental impacts associated with the proposed standards. Both adverse and beneficial impacts in such areas as air and water pollution, increased solid waste disposal, and increased energy consumption are discussed.

2.6 IMPACT ON EXISTING SOURCES

Section 111 of the Act defines a new source as "any stationary source, the construction or modification of which is commenced" after the proposed standards are published in the Federal Register. An existing source is redefined as a new source if "modified" or "reconstructed" as defined in amendments to the general provisions of Subpart A of 40 CFR Part 60, which were promulgated in the Federal Register on December 16, 1975 (40 FR 58416).

Any physical or operational change to an existing facility which results in an increase in the emission rate of any pollutant for which a standard applies is considered a modification. Reconstruction, on the other hand, means the replacement of components of an existing facility to the extent that the fixed capital cost exceeds 50 percent of the cost of constructing a comparable entirely new source and that it be technically and economically feasible to meet the applicable standards. In such cases, reconstruction is equivalent to a new construction.

Promulgation of a standard of performance requires States to establish standards of performance for existing sources in the same industry under Section 111(d) of the Act if the standard for new sources limits emissions of a designated pollutant (i.e., a pollutant for which air quality criteria have not been issued under Section 108 or which has not been listed as a hazardous pollutant under Section 112). If a State does not act, EPA must establish such standards. General provisions outlining procedures for control of existing sources under Section 111(d) were promulgated on November 17, 1975, as Subpart B of 40 CFR Part 60 (40 FR 53340).

2.7 REVISION OF STANDARDS OF PERFORMANCE

Congress was aware that the level of air pollution control achievable by any industry may improve with technological advances. Accordingly, Section 111 of the Act provides that the Administrator "shall, at least every 4 years, review and, if appropriate, revise" the standards. Revisions are made to ensure that the standards continue to reflect the best systems that become available in the future. Such revisions will not be retroactive but will apply to stationary sources constructed or modified after the proposal of the revised standards.

3. VOLATILE ORGANIC LIQUID STORAGE

3.1 THE VOLATILE ORGANIC LIQUID STORAGE INDUSTRY

Volatile organic liquid (VOL) storage vessels are primarily located at chemical manufacturing and producing facilities and at bulk liquid transfer terminals. An economic description of these industries is contained in Section 9.1. The storage of VOL within these industries is described below.

3.1.1 Industrial Service (Chemical Manufacturing)

Tanks are used for storing a variety of organic liquids, including raw materials, final products, and/or usable byproducts, as well as waste tars, residues, and other wastes. Available data were analyzed to determine the number of tanks in the nation containing volatile organic liquids.[1,2,3] The 1977 industrial tank population was found to be 27,540.[4]

The vapor pressure of the material to be stored is a major factor in choosing the tank type to be used. In practice, fixed roof tanks are predominantly used for storing materials with vapor pressures up to 34.5 kPa; floating-roof tanks are also used to store materials in the same range. Table 3-1 gives the distribution of tanks nationally, according to the vapor pressure of the VOLs stored in fixed and floating roof tanks. Other factors such as material stability, safety hazards, and multiple use also affect the choice of tank type for a particular organic liquid. Table 3-2 gives the national tank distribution by storage capacity for fixed roof and floating roof tanks.

3.1.2 Terminal Service

A terminal is a nonmanufacturing site that stores commodities in bulk quantity. Only those terminals that store VOL were of concern to this study. Telephone directories of selected cities were searched for terminal listings. As a result of this survey, it was determined that data obtained from the Independent Liquid Terminal Association (ILTA)

Table 3-1. NATIONAL INDUSTRIAL VOL TANK DISTRIBUTION ACCORDING TO VAPOR PRESSURE (1977)

Vapor pressure, (kPa)	Number of tanks nationwide		
	Fixed-roof	Floating-roof	Total
0 - 3.5	16,350	170	16,520
3.5 - 6.9	3,560	100	3,660
6.9 - 10.3	1,950	70	2,020
10.3 - 34.5	3,800	790	4,590
34.5 - 58.6	500	40	540
≥58.6	190	20	210
Total	26,350	1,190	27,540
Percent of Total	95.7	4.3	100.

Table 3-2. NATIONAL INDUSTRIAL VOL TANK DISTRIBUTION ACCORDING TO TANK SIZE (1977)

Tank size, (m^3)	Number of tanks nationwide		
	Fixed-roof	Floating-roof	Total
0 - 75	12,270	20	12,290
75 - 150	3,910	30	3,940
150 - 375	3,770	180	3,950
375 - 3,750	5,840	610	6,450
3,750 - 15,000	520	320	840
≥15,000	40	30	70
Total	26,350	1,190	27,540
Percent of Total	95.7	4.3	100.

would serve as a sufficient approximation of the national terminal population.[5] Sixty-eight ILTA member companies operate more than 150 terminals. Of these, 82 terminals handle VOLs. It was assumed that any terminal storing VOL devoted its entire storage volume to VOL. Statistics for the tanks in the 82 VOL terminals are given in Table 3-3.

3.2 STORAGE TANKS

3.2.1 Types of Storage Tanks

There are three types of vessels of concern in developing standards of performance for VOL storage vessels:

- fixed roof tanks;
- external floating roof tanks; and
- internal floating roof tanks.

These tanks are cylindrical in shape with the axis oriented perpendicular to the foundation. The tanks are almost exclusively above ground. Below-ground vessels and horizontal vessels (i.e. with the axis parallel to the foundation) also can be used in VOL service. However, these types of vessels are much less common in VOL service than the other tank types listed above and, for the most part, are less than 100 cubic meters (26,400 gallons) in capacity. Consequently, their contribution to nationwide VOL storage emissions is minor. Controls applicable to horizontal tanks are limited primarily to closed vent systems and control devices as discussed in Chapter 4. Since their contribution to nationwide emissions is minor, no detailed equipment description is provided for these types of roofs. For a similar reason, no detailed equipment description is provided for pressure vessels. This section, therefore, addresses only fixed roof, external floating and internal floating roof tanks.

3.2.1.1 Fixed Roof Tanks. Of currently used tank designs, the fixed roof tank is the least expensive to construct and is generally considered as the minimum acceptable equipment for the storage of VOLs. A typical fixed roof tank, which is shown in Figure 3-1, consists of a cylindrical steel shell with a cone- or dome-shaped roof that is permanently affixed to the tank shell. A breather valve (pressure-vacuum valve), which is commonly installed on many fixed roof tanks, allows the tank to

Table 3-3. STATISTICS FOR THE NATIONAL TANK POPULATION IN VOL TERMINAL STORAGE (1979)

CAPACITY

Total capacity in data base: 1.390 x 10^{10} liters (3,670 x 10^6 gal)

Average capacity for a terminal: 1.78 x 10^8 liters (47 x 10^6 gal)

Median capacity for a terminal: 9.35 x 10^7 liters (25 x 10^6 gal)

NUMBER OF TANKS

Total number of tanks at terminals in data base: 4,212

Average number of tanks per terminal: 54

Median number of tanks per terminal: 37.5

SMALLEST TANK[a]

Average size of smallest tank: 1.2 x 10^6 liters (318.9 x 10^3 gal)

Median size of smallest tank: 1.59 x 10^5 liters (42 x 10^3 gal)

AVERAGE TANK SIZE: 3.3 x 10^6 liters (872 x 10^3 gal)

LARGEST TANK[b]

Average size of largest tank: 1.36 x 10^7 liters (3,599 x 10^3 gal)

Median size of largest tank: 9.22 x 10^6 liters (2,436 x 10^3 gal)

---

[a] Volume of the smallest tank at each terminal.

[b] Volume of the largest tank at each terminal.

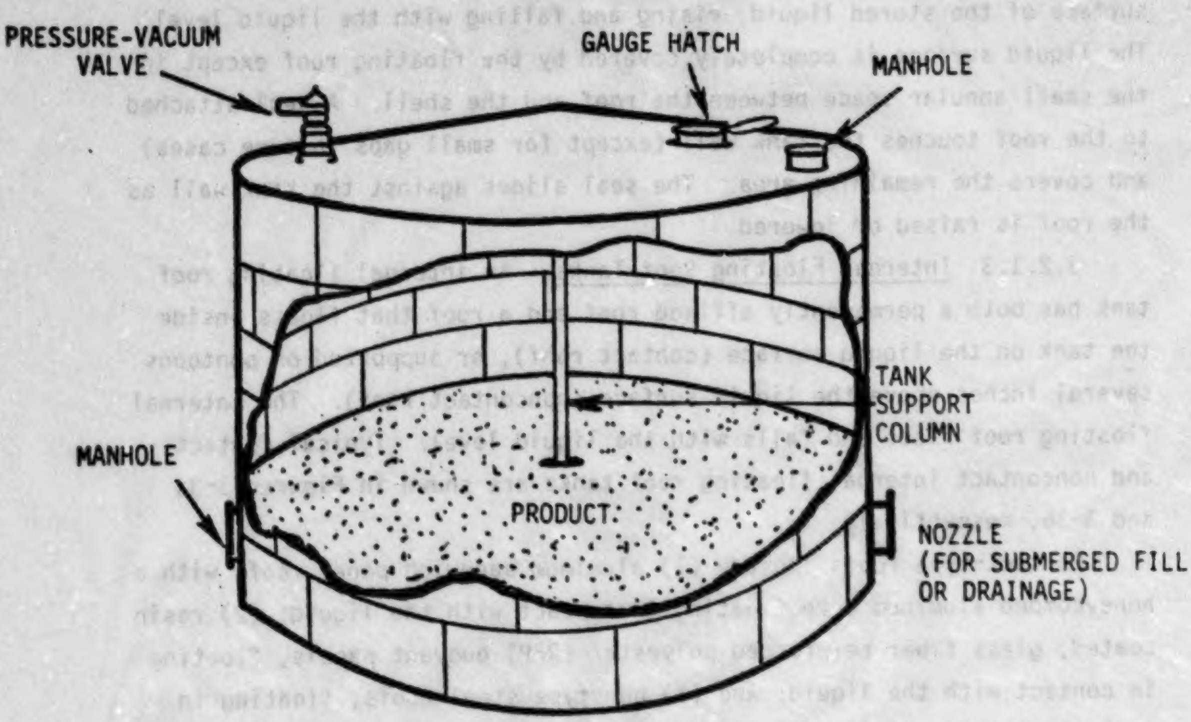

PRESSURE-VACUUM VALVE
GAUGE HATCH
MANHOLE
TANK SUPPORT COLUMN
MANHOLE
PRODUCT
NOZZLE (FOR SUBMERGED FILL OR DRAINAGE)

Figure 3-1. Typical fixed roof tank.

operate at a slight internal pressure or vacuum. Because this valve prevents the release of vapors only during very small changes in temperature, barometric pressure, or liquid level, the emissions from a fixed roof tank can be appreciable.

3.2.1.2 External Floating Roof Tanks. A typical external floating roof tank is shown in Figure 3-2. This type of tank consists of a cylindrical steel shell equipped with a deck or roof that floats on the surface of the stored liquid, rising and falling with the liquid level. The liquid surface is completely covered by the floating roof except in the small annular space between the roof and the shell. A seal attached to the roof touches the tank wall (except for small gaps in some cases) and covers the remaining area. The seal slides against the tank wall as the roof is raised or lowered.

3.2.1.3 Internal Floating Roof Tanks. An internal floating roof tank has both a permanently affixed roof and a roof that floats inside the tank on the liquid surface (contact roof), or supported on pontoons several inches above the liquid surface (noncontact roof). The internal floating roof rises and falls with the liquid level. Typical contact and noncontact internal floating roof tanks are shown in Figures 3-3a and 3-3b, respectively.

Contact-type roofs include (1) aluminum sandwich panel roofs with a honeycombed aluminum core floating in contact with the liquid; (2) resin coated, glass fiber reinforced polyester (RFP) buoyant panels, floating in contact with the liquid; and (3) pan-type steel roofs, floating in contact with the liquid with or without the aid of pontoons. The majority of contact internal floating roofs currently in VOL service are steel-pan type or aluminum sandwich panel type. The RFP roofs are less common.

Several variations of the pan-type contact steel roof exist. The design may include bulkheads, or open compartments, around the perimeter of the roof to minimize and/or localize the effects of liquid that may leak or spill onto the deck. Alternately, the bulkheads may be covered to form sealed compartments (i.e., pontoons), or the entire pan may be covered to form a sealed double deck steel floating roof. Construction is generally welded steel.

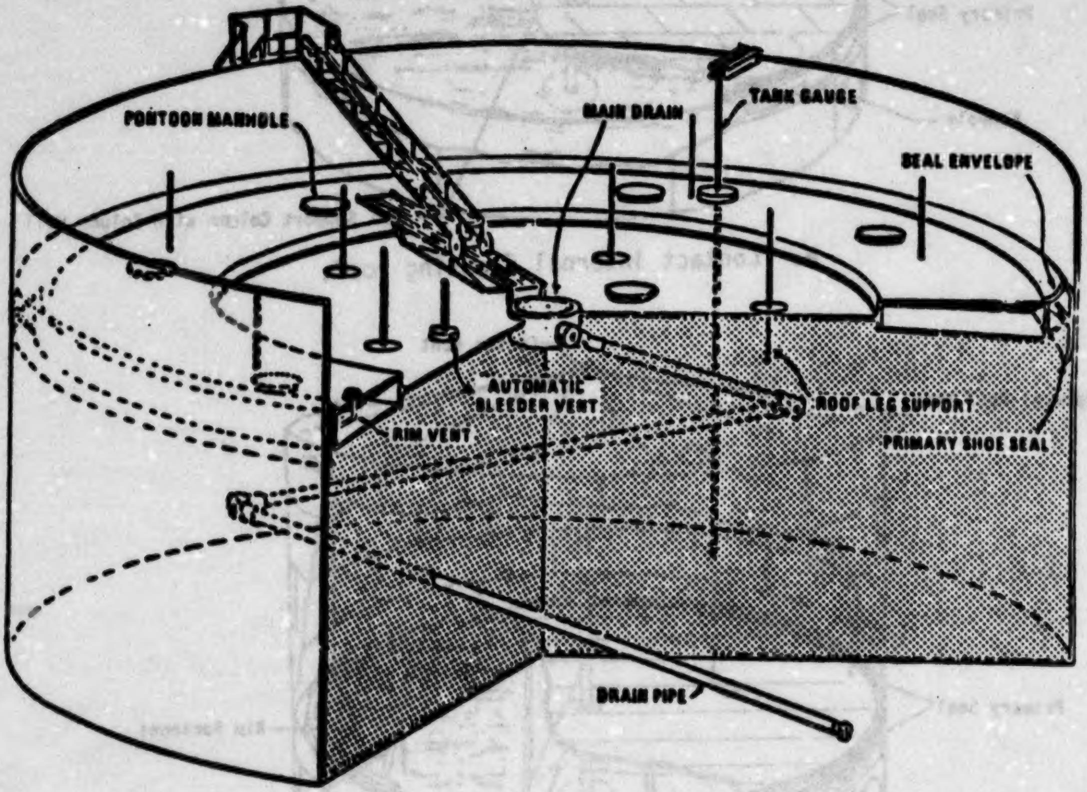
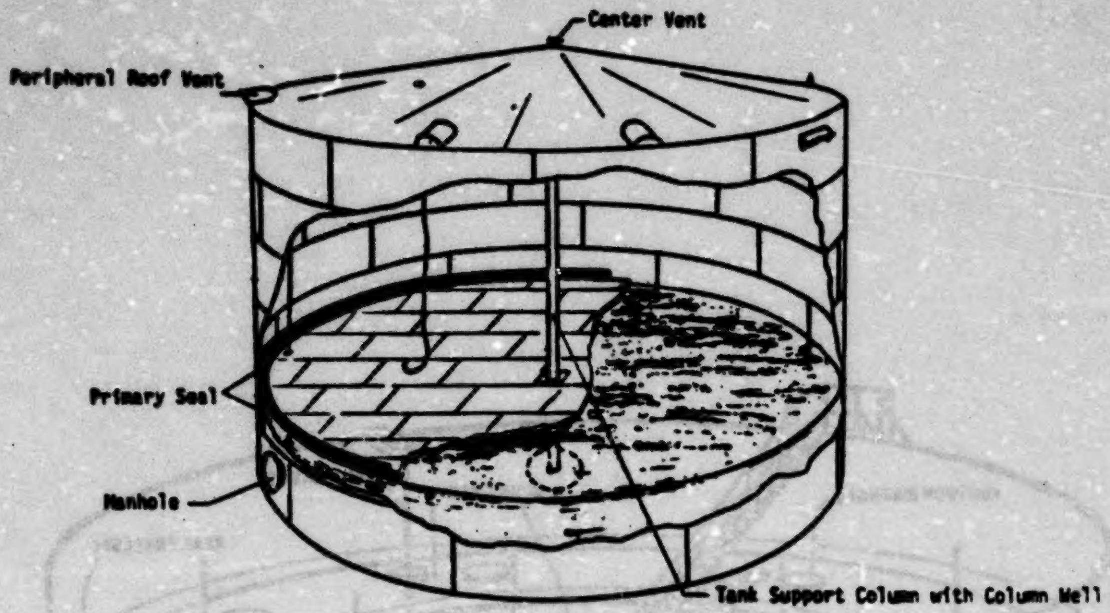
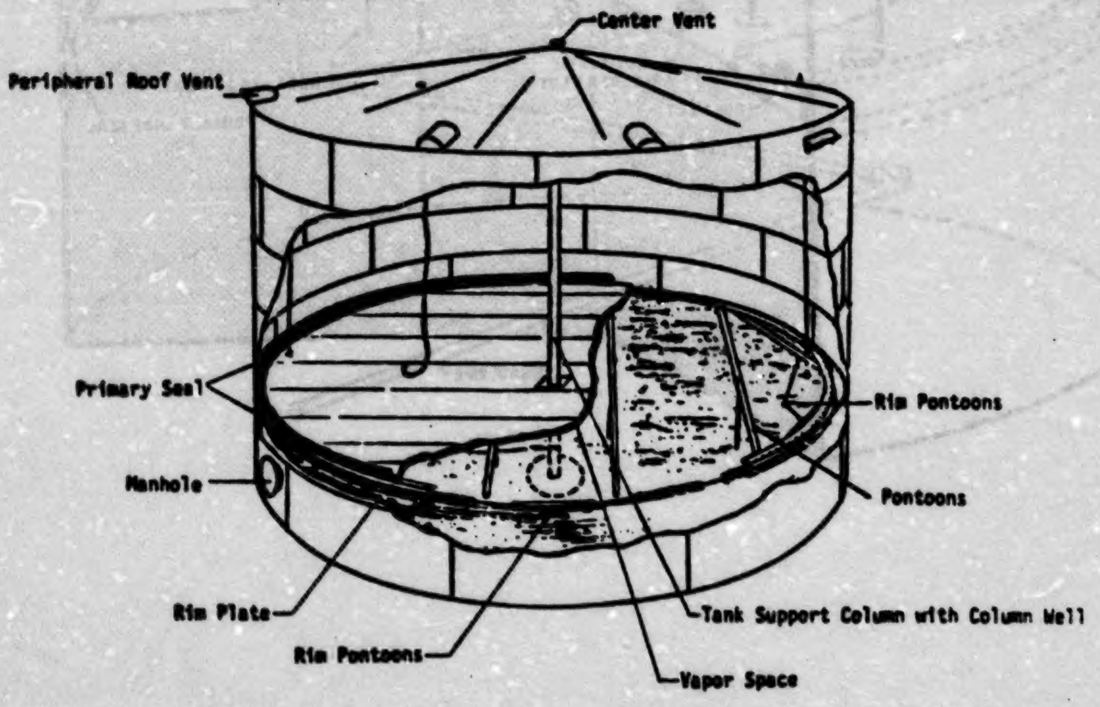

PONTOON MANHOLE
MAIN DRAIN
TANK GAUGE
SEAL ENVELOPE
AUTOMATIC BLEEDER VENT
RIM VENT
ROOF LEG SUPPORT
PRIMARY SHOE SEAL
DRAIN PIPE

Figure 3-2. External floating roof tank (pontoon type).


Center Vent
Peripheral Roof Vent
Primary Seal
Manhole
Tank Support Column with Column Well

a. Contact internal floating roof.


Center Vent
Peripheral Roof Vent
Primary Seal
Rim Pontoons
Manhole
Pontoons
Rim Plate
Tank Support Column with Column Well
Rim Pontoons
Vapor Space

b. Noncontact internal floating roof.

Figure 3-3. Internal floating roof tanks.

Noncontact-type roofs typically consist of an aluminum deck on an aluminum grid framework supported above the liquid surface by tubular aluminum pontoons. The deck skin for the noncontact-type floating roofs typically is constructed of rolled aluminum sheets (about 1.5 m wide and 0.58 mm thick). The overlapping aluminum sheets are joined by bolted aluminum clamping bars that run perpendicular to the pontoons to improve the rigidity of the frame. The deck skin seams can be metal on metal or gasketed with a polymeric material. The pontoons and clamping bars form the structural frame of the floating roof. The presence of deck seams in the noncontact internal floating roof design contributes to emissions from the internal floating roof tank. Aluminum sandwich panel contact-type internal floating roofs share this design feature. The sandwich panels are joined with bolted mechanical fasteners that are similar in concept to the noncontact deck skin clamping bars. Steel-pan contact internal floating roofs are constructed of welded steel sheets and have no deck seams. Similarly, the resin-coated, reinforced fiberglass panel roofs have no apparent deck seams. The panels are butted and lapped with resin-impregnated fiberglass fabric strips. The significance of deck seams to emissions from internal floating roof tanks is addressed in Chapter 4.

It should be recognized that the roof physically occupies a finite volume of space that takes away from the maximum liquid storage capacity of the tank. When completely full, the floating roof touches or nearly touches the fixed roof. Consequently, the effective height of the tank decreases, thus limiting the storage capacity. The reduction in the effective height varies from about 1 to 2 feet depending on the type and design of the floating roof employed.

All types of internal floating roofs, like external floating roofs, commonly incorporate flexible perimeter seals or wipers that slide against the tank wall as the roof moves up and down. These seals are discussed in detail in Section 3.2.2.2. Circulation vents and an open vent at the top of the fixed roof are generally provided to minimize the possibility of hydrocarbon vapors accumulating in concentrations approaching the flammable range.

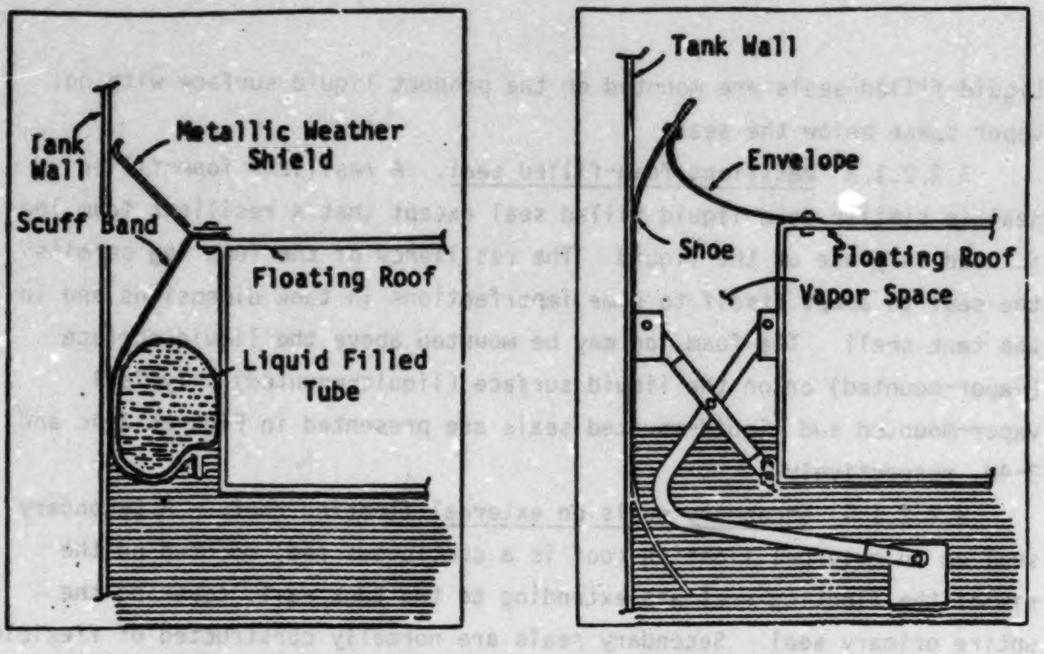
3.2.2 Types of Floating Roof Perimeter Seals

3.2.2.1 External Floating Roof Seals. Regardless of tank design, a floating roof requires a closure device to seal the gap between the tank wall and the roof perimeter. A primary seal, the lower seal of a two-seal system, can be made from various materials suitable for organic liquids service. The basic designs available for primary seals are (1) mechanical shoe seals, (2) liquid-filled seals, and (3) (vapor- or liquid-mounted) resilient foam log seals. Figure 3-4 depicts these three general types of seals.

One major difference in seal system design is the way in which the seal is mounted with respect to the liquid. Figure 3-4c shows a vapor space between the liquid surface and seal, whereas, in Figures 3-4a and 3-4d, the seals are resting on the liquid surface. These liquid-filled tube and resilient foam seals are classified as liquid- or vapor-mounted seals depending on their location. Mechanical shoe seals are different in design from liquid-filled or resilient foam log seals and cannot be characterized as liquid- or vapor-mounted. However, because the shoe and envelope combination precludes communication between the annular vapor space above the liquid and the atmosphere (see Figure 3-4b), the performance of a mechanical shoe seal is more like that of a liquid-mounted seal than a vapor-mounted seal.

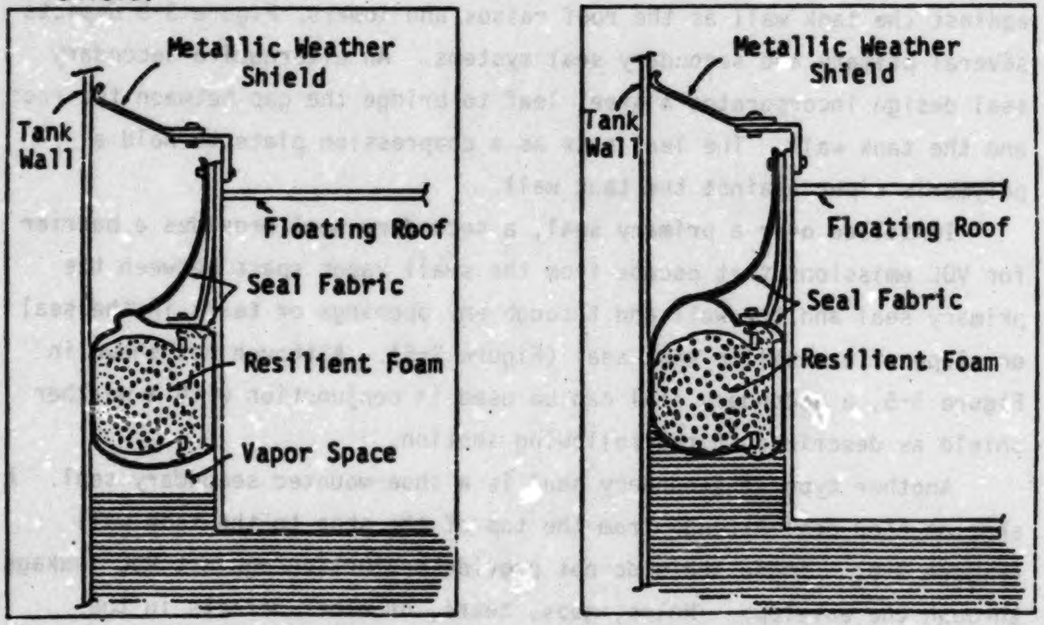
3.2.2.1.1 Mechanical shoe seal. A mechanical shoe seal, otherwise known as a "metallic shoe seal" (Figure 3-4b), is characterized by a metallic sheet (the "shoe") 75 to 130 cm (30 to 51 in) high held against the vertical tank wall. The shoe is connected by braces to the floating roof and is held tightly against the wall by springs or weighted levers. A flexible, coated fabric (the "envelope") is suspended from the shoe seal to the floating roof to form a vapor barrier over the annular space between the roof and the primary seal.

3.2.2.1.2 Liquid-filled seal. A liquid-filled seal (Figure 3-4a) may be a tough fabric band or envelope filled with a liquid, or it may be a flexible polymeric tube 20 cm to 25 cm (8 inch to 10 inch) in diameter filled with a liquid and sheathed with a tough fabric scuff band. The liquid is commonly a petroleum distillate or other liquid that will not contaminate the stored product if the tube ruptures.


Tank Wall
Metallic Weather Shield
Scuff Band
Floating Roof
Liquid Filled Tube
Tank Wall
Envelope
Shoe
Floating Roof
Vapor Space

a. Liquid-filled seal with weather shield.

b. Metallic shoe seal.


Metallic Weather Shield
Tank Wall
Floating Roof
Seal Fabric
Resilient Foam
Vapor Space
Metallic Weather Shield
Tank Wall
Floating Roof
Seal Fabric
Resilient Foam

c. Vapor-mounted resilient foam-filled seal with weather shield.

d. Liquid-mounted resilient foam-filled seal with weather shield.

Figure 3-4. Primary seals.

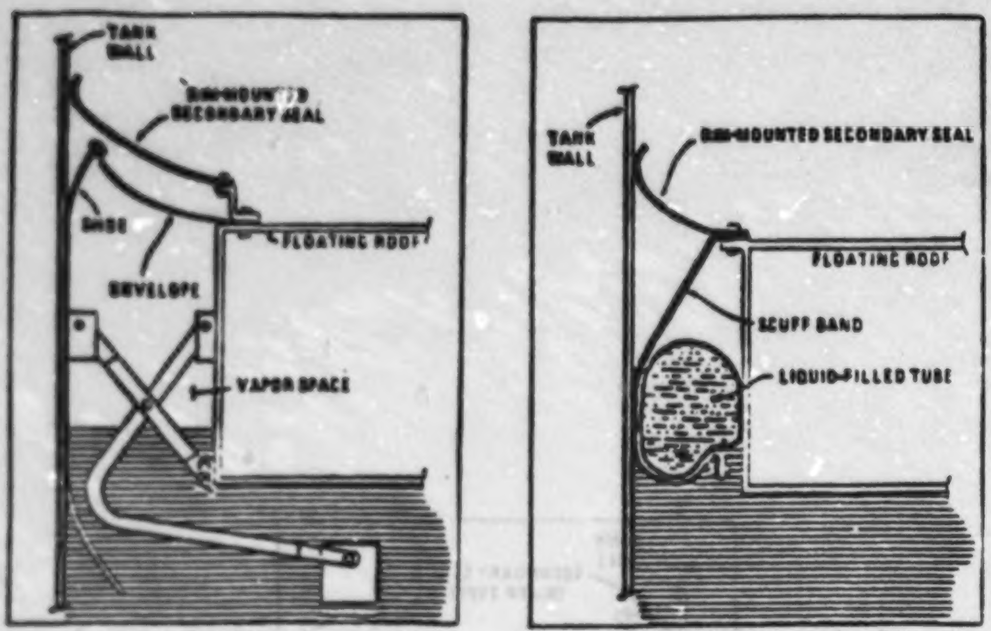
Liquid-filled seals are mounted on the product liquid surface with no vapor space below the seal.

3.2.2.1.3 Resilient foam-filled seal. A resilient foam-filled seal is similar to a liquid-filled seal except that a resilient foam log is used in place of the liquid. The resiliency of the foam log permits the seal to adapt itself to some imperfections in tank dimensions and in the tank shell. The foam log may be mounted above the liquid surface (vapor-mounted) or on the liquid surface (liquid-mounted). Typical vapor-mounted and liquid-mounted seals are presented in Figures 3-4c and 3-4d, respectively.

3.2.2.1.4 Secondary seals on external floating roofs. A secondary seal on an external floating roof is a continuous seal mounted on the rim of the floating roof and extending to the tank wall, covering the entire primary seal. Secondary seals are normally constructed of flexible polymeric materials and mounted such that they provide a wiping action against the tank wall as the roof raises and lowers. Figure 3-5 depicts several primary and secondary seal systems. An alternative secondary seal design incorporates a steel leaf to bridge the gap between the roof and the tank wall. The leaf acts as a compression plate to hold a polymeric wiper against the tank wall.

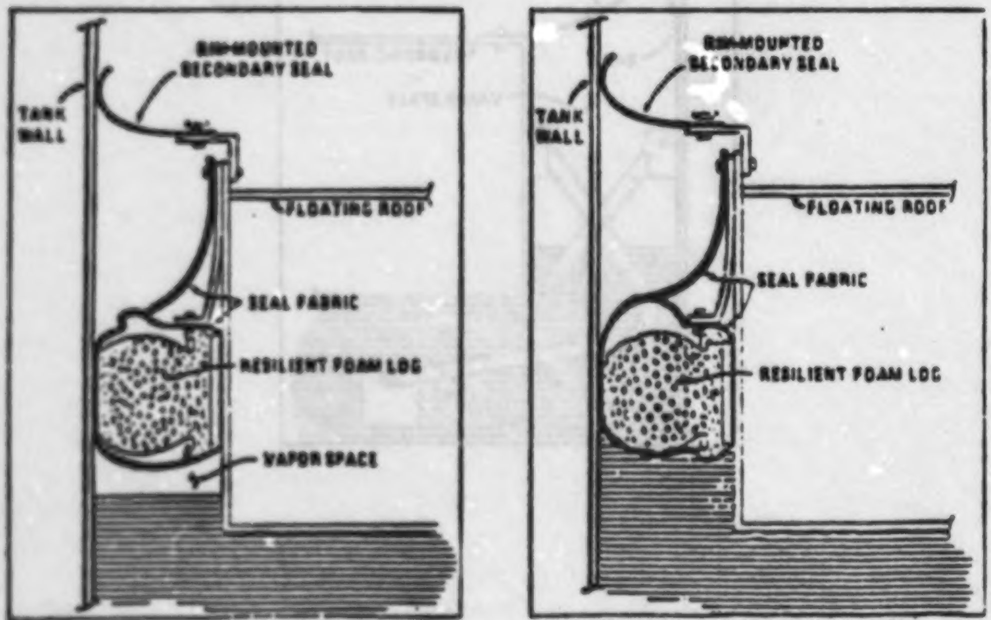
Installed over a primary seal, a secondary seal provides a barrier for VOC emissions that escape from the small vapor space between the primary seal and the wall and through any openings or tears in the seal envelope of a metallic shoe seal (Figure 3-5). Although not shown in Figure 3-5, a secondary seal can be used in conjunction with a weather shield as described in the following section.

Another type of secondary seal is a shoe-mounted secondary seal. A shoe-mounted seal extends from the top of the shoe to the tank wall (Figure 3-6). These seals do not provide protection against VOC leakage through the envelope. Holes, gaps, tears, or other defects in the envelope can permit direct communication between the saturated vapor under the envelope and the atmosphere. Wind can enter this space through envelope defects, flow around the circumference of the tank, and exit with saturated or nearly saturated VOC vapors.


TANK WALL
RIM-MOUNTED SECONDARY SEAL
SHOE
ENVELOPE
FLOATING ROOF
VAPOR SPACE
TANK WALL
RIM-MOUNTED SECONDARY SEAL
FLOATING ROOF
SCUFF BAND
LIQUID-FILLED TUBE

a. Shoe seal with rim-mounted secondary seal.

b. Liquid-filled seal with rim-mounted secondary seal.


RIM-MOUNTED SECONDARY SEAL
TANK WALL
FLOATING ROOF
SEAL FABRIC
RESILIENT FOAM LOG
VAPOR SPACE
RIM-MOUNTED SECONDARY SEAL
TANK WALL
FLOATING ROOF
SEAL FABRIC
RESILIENT FOAM LOG

c. Resilient foam seal (vapor-mounted) with rim-mounted secondary seal.

d. Resilient foam seal (liquid-mounted) with rim-mounted secondary seal.

Figure 3-5 (a-d). Rim-mounted secondary seals on external floating roofs.[3]

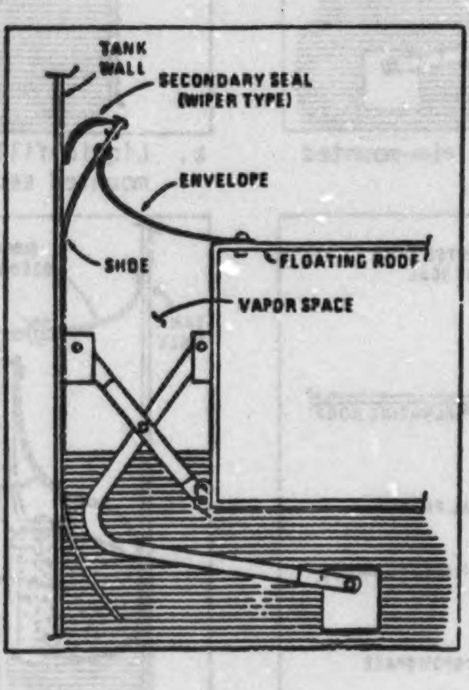

TANK WALL
SECONDARY SEAL (WIPER TYPE)
ENVELOPE
SHOE
FLOATING ROOF
VAPOR SPACE

Figure 3-6. Metallic shoe seal with shoe-mounted secondary seal.[3]

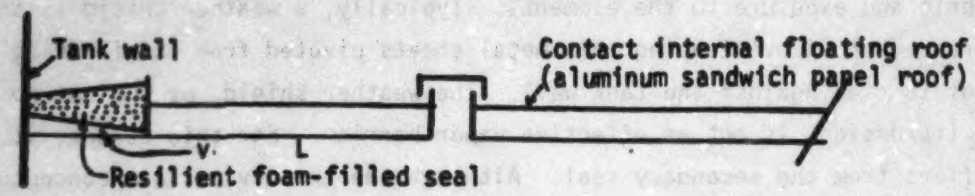
3.2.2.1.5 Weather shield. A weather shield (Figures 3-4a, 3-4c, and 3-4d) may be installed over the primary seal or the primary and secondary seals, to protect it, or them, from deterioration caused by debris and exposure to the elements. Typically, a weather shield is an arrangement of overlapping thin metal sheets pivoted from the floating roof to ride against the tank wall. The weather shield, by the nature of its design, is not an effective vapor barrier. For this reason, it differs from the secondary seal. Although the two devices are conceptually similar in design, they are designed for and serve different purposes.

3.2.2.2 Internal Floating-Roof Tank Seals. Internal floating roofs typically incorporate one of two types of flexible, product-resistant primary seals: resilient foam-filled seals or wiper seals. Similar to those employed on external floating roofs, each of these seals closes the annular vapor space between the edge of the floating roof and the tank shell. They are designed to compensate for small irregularities in the tank shell, and allow the roof to move freely up and down in the tank without binding.

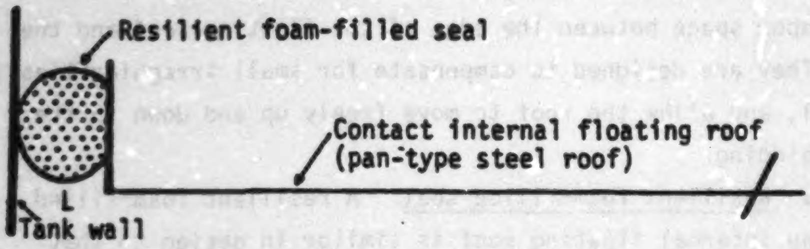
3.2.2.2.1 Resilient foam-filled seal. A resilient foam-filled seal used on an internal floating roof is similar in design to that described in Section 3.2.2.1.3 for external floating roofs. Two types of resilient foam-filled seals for internal floating roofs are shown in Figures 3-7a and 3-7b. These seals can either be mounted in contact with the liquid surface (liquid-mounted) or several centimeters above the liquid surface (vapor-mounted).

Resilient filled seals work on the principle of expansion and contraction of a resilient material to maintain contact with the tank shell while accommodating varying annular rim space widths. These seals consist of a core of open-cell foam encapsulated in a coated fabric. The elasticity of the foam core pushes the fabric into contact with the tank shell. The seals are attached to a mounting on the deck perimeter and are continuous around the circumference. Urethane coated nylon fabric and polyurethane foam are commonly employed materials. For emission control, it is important that the mounting and radial seal joints be vapor-tight and that the seal be in substantial contact with the tank shell.[6]

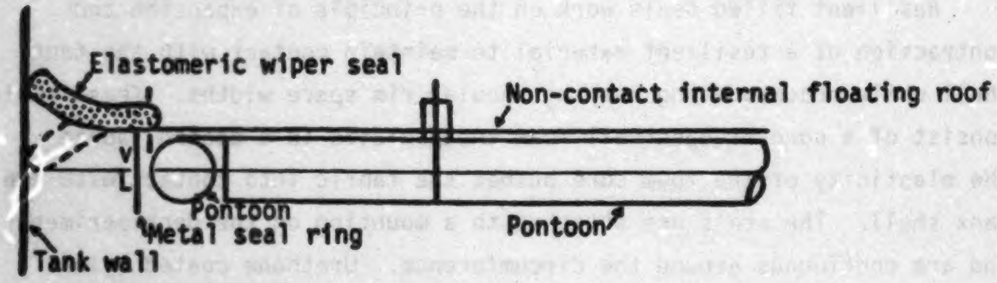
a. Resilient foam-filled seal (vapor-mounted).


Tank wall
Contact internal floating roof
(aluminum sandwich panel roof)
V
L
Resilient foam-filled seal

b. Resilient foam-filled seal (liquid-mounted).


Resilient foam-filled seal
Contact internal floating roof
(pan-type steel roof)
L
Tank wall

c. Elastomeric wiper seal.


Elastomeric wiper seal
Non-contact internal floating roof
V
L
Pontoon
Metal seal ring
Pontoon
Tank wall

Note: v - vapor
L - liquid

Figure 3-7. Typical flotation devices and perimeter seals for internal floating roofs.

3.2.2.2.2 Primary wiper seals. Wiper seals are commonly used as primary seals for internal floating roof tanks. This type of seal is depicted in Figure 3-7c.

Wiper seals generally consist of a continuous annular blade of flexible material fastened to a mounting on the deck perimeter, spanning the annular rim space, and contacting the tank shell. The mounting is such that the blade is flexed, and its elasticity provides a sealing pressure against the tank shell. A vapor space exists between the liquid stock and the bottom of the seal; such seals are vapor-mounted. For emission control, it is important that the mounting be vapor-tight, that the seal be continuous around the circumference, and that the blade be in substantial contact with the tank shell.[6]

Two types of wipers are commonly used. One type consists of a cellular, elastomeric material tapered in cross section with the thicker portion at the mounting. Buna-N rubber is a commonly-used material. All radial joints in the blade are joined.[6]

A second type of wiper seal construction uses a foam core wrapped with a coated fabric. Urethane on nylon fabric and polyurethane foam are common materials. The core provides the flexibility and support while the fabric provides the vapor barrier and wear surface.[6]

A third type of wiper seal consists of overlapping segments of seal material (shingle-type seal). Single-type seals differ from the wiper seals discussed previously in that they do not provide a continuous vapor barrier.

3.2.2.2.3 Secondary seals for internal floating roof tanks. Secondary seals may be used to provide some additional evaporative loss control over that achieved by the primary seal. The secondary seal would be mounted to an extended vertical rim plate, above the primary seal, as shown in Figure 3-8. Secondary seals can be either an elastomeric wiper seal or a resilient foam-filled seal as described in Sections 3.2.2.2.2 and 3.2.2.2.1, respectively. For a given roof design, the use of a secondary seal further limits the operating capacity of a tank due to the need to avoid interference of the seal with the fixed roof rafters when the tank is filled. Currently, secondary seals are not commonly used on internal floating roof tanks[6].

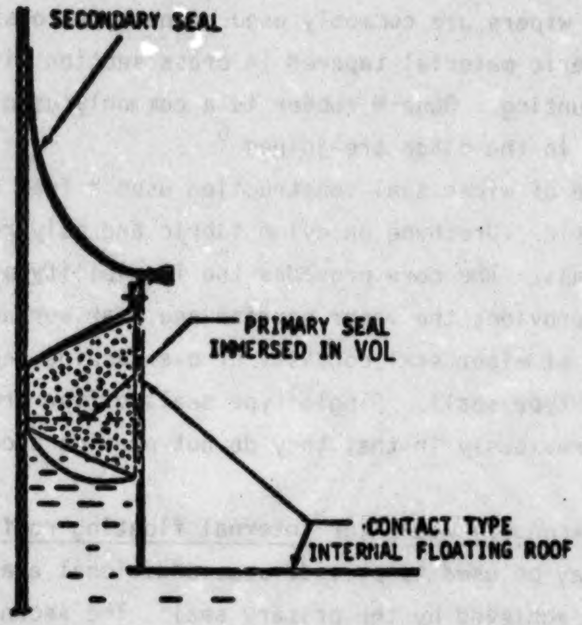

SECONDARY SEAL
PRIMARY SEAL IMMERSED IN VOL
CONTACT TYPE INTERNAL FLOATING ROOF

Figure 3-8. Rim mounting of a secondary seal on internal floating roof.[8]

3.2.3 Types of Internal Floating Roof Deck Fittings

The majority of Section 3.2.3 largely is from a draft American Petroleum Institute publication[6] that is expected to be published in June, 1983.

There are numerous fittings that penetrate or are attached to an internal floating roof. These fittings serve to accommodate structural support members or to allow for operational functions.[6] A cross section of an internal floating roof tank showing typical fittings is depicted in Figure 3-9.[7] The fittings can be a source of evaporative loss, in that, they require penetrations in the deck. Other accessories are used that do not penetrate the deck and are not, therefore, sources of evaporative loss. The most common fittings with relevance to controllable vapor losses are described in the following sections.[6]

3.2.3.1 Access Hatches. An access hatch consists of an opening in the deck with a peripheral vertical well attached to the deck and a removable cover to close the opening. An access hatch is sized to provide for passage of workers and materials through the deck for construction or servicing. The cover can rest directly on the well, or a gasketed connection can be used to reduce evaporative loss. Bolting the cover to the well provides further loss reduction. With noncontact decks, the well should extend down into the liquid stock to seal off the vapor space below the deck.[6] Figure 3-10a depicts an access hatch that is suitable for use on a steel contact internal floating roof.

3.2.3.2 Column Wells. The most common fixed roof designs are normally supported from inside the tank by means of vertical columns, which necessarily penetrate the floating deck. (Some fixed roofs are entirely self-supporting and, therefore, have no support columns.) Columns are made of pipe with circular cross sections or of structural shapes with irregular cross sections. The number of columns varies with tank diameter, from a minimum of one to over 50 for very large tanks.[6] Figure 3-10b depicts a column well for a built-up column.

The columns pass through deck openings with peripheral vertical wells. With noncontact decks, the well should extend down into the liquid stock. Generally, a closure device exists between the top of the well and the column. Several proprietary designs exist for this closure,

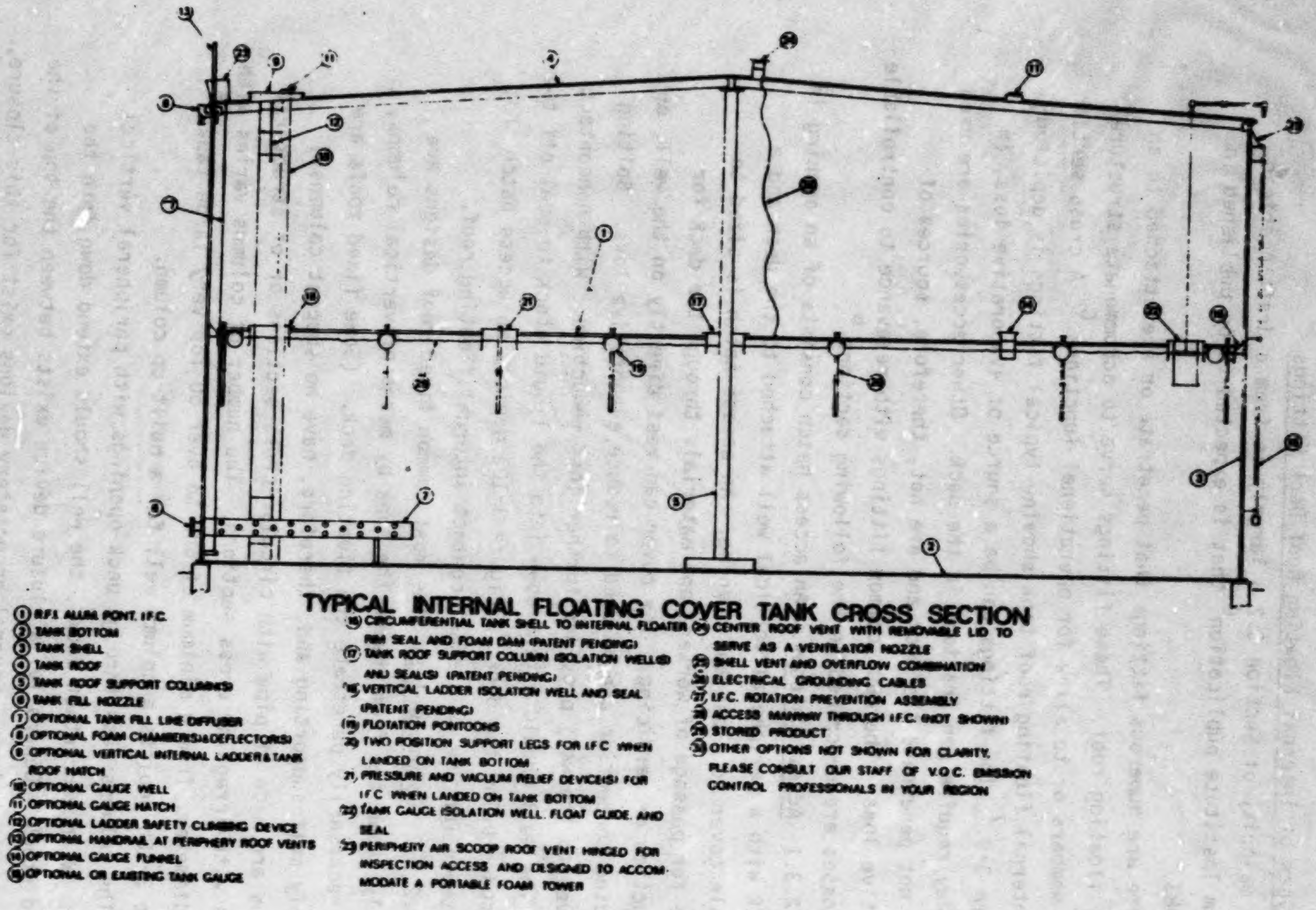
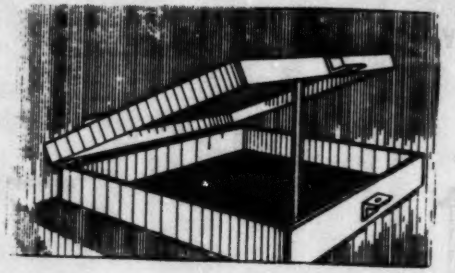
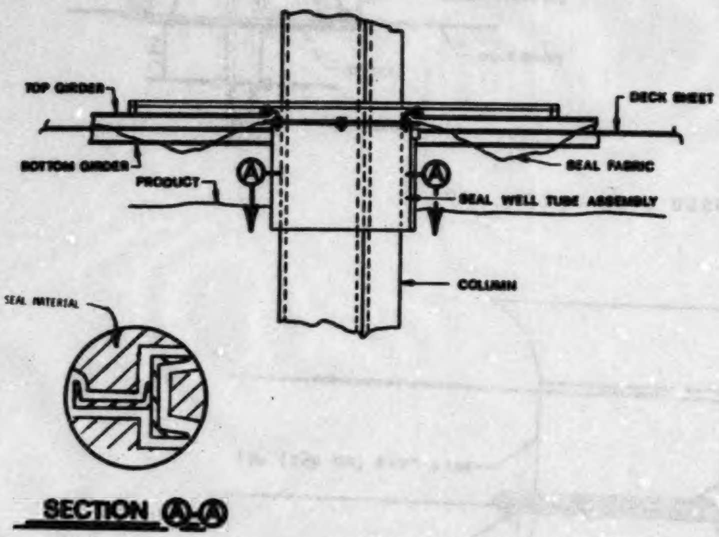

TYPICAL INTERNAL FLOATING COVER TANK CROSS SECTION
① R.F.I. ALUM. PONT. I.F.C.
② TANK BOTTOM
③ TANK SHELL
④ TANK ROOF
⑤ TANK ROOF SUPPORT COLUMN(S)
⑥ TANK FILL NOZZLE
⑦ OPTIONAL TANK FILL LINE DIFFUSER
⑧ OPTIONAL FOAM CHAMBER(S)&DEFLECTOR(S)
⑨ OPTIONAL VERTICAL INTERNAL LADDER & TANK ROOF HATCH
⑩ OPTIONAL GAUGE WELL
⑪ OPTIONAL GAUGE HATCH
⑫ OPTIONAL LADDER SAFETY CLIMBING DEVICE
⑬ OPTIONAL HANDRAIL AT PERIPHERY ROOF VENTS
⑭ OPTIONAL GAUGE FUNNEL
⑮ OPTIONAL OR EXISTING TANK GAUGE
⑯ CIRCUMFERENTIAL TANK SHELL TO INTERNAL FLOATER RIM SEAL AND FOAM DAM (PATENT PENDING)
⑰ TANK ROOF SUPPORT COLUMN ISOLATION WELL(S) AND SEAL(S) (PATENT PENDING)
⑱ VERTICAL LADDER ISOLATION WELL AND SEAL (PATENT PENDING)
⑲ FLOTATION PONTOONS
⑳ TWO POSITION SUPPORT LEGS FOR I.F.C. WHEN LANDED ON TANK BOTTOM
㉑ PRESSURE AND VACUUM RELIEF DEVICE(S) FOR I.F.C. WHEN LANDED ON TANK BOTTOM
㉒ TANK GAUGE ISOLATION WELL, FLOAT GUIDE, AND SEAL
㉓ PERIPHERY AIR SCOOP ROOF VENT HINGED FOR INSPECTION ACCESS AND DESIGNED TO ACCOMMODATE A PORTABLE FOAM TOWER
㉔ CENTER ROOF VENT WITH REMOVABLE LID TO SERVE AS A VENTILATOR NOZZLE
㉕ SHELL VENT AND OVERFLOW COMBINATION
㉖ ELECTRICAL GROUNDING CABLES
㉗ I.F.C. ROTATION PREVENTION ASSEMBLY
㉘ ACCESS MANWAY THROUGH I.F.C. (NOT SHOWN)
㉙ STORED PRODUCT
㉚ OTHER OPTIONS NOT SHOWN FOR CLARITY. PLEASE CONSULT OUR STAFF OF V.O.C. EMISSION CONTROL PROFESSIONALS IN YOUR REGION

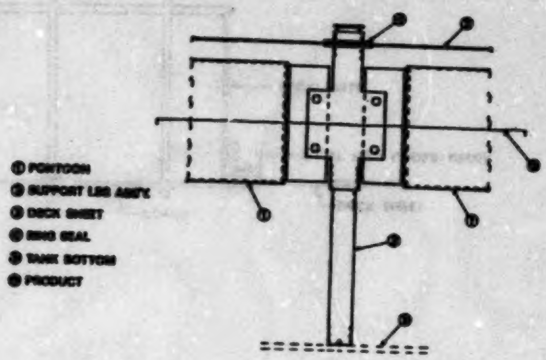
Figure 3-9. Typical internal floating roof tank cross section.[7]



a. Access hatch[9]

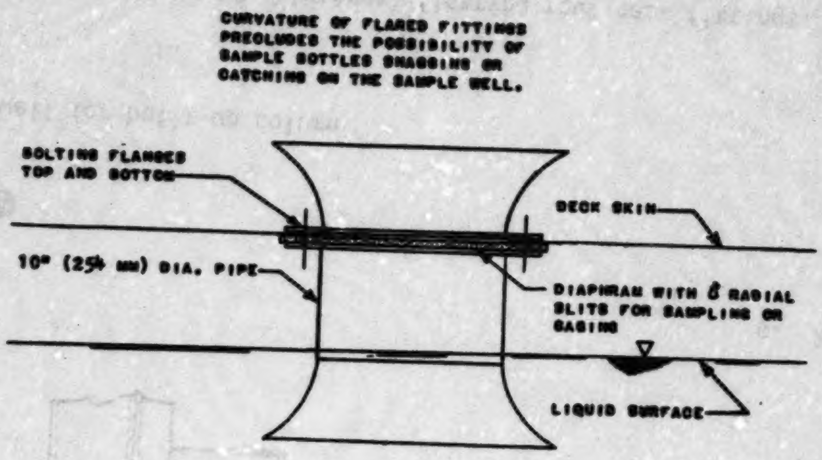

TOP GIRDER
DECK SHEET
BOTTOM GIRDER
SEAL FABRIC
PRODUCT
A
A
SEAL WELL TUBE ASSEMBLY
COLUMN
SEAL MATERIAL
SECTION A-A

b. Column well for built-up column 7

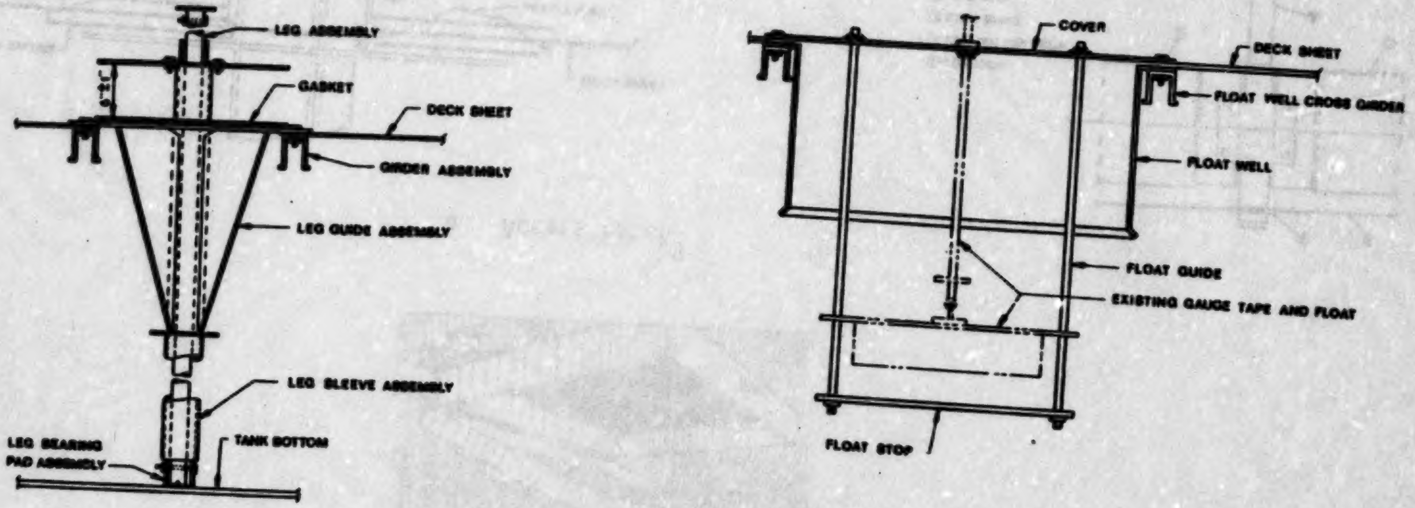

① PONTOON
② SUPPORT LEG ASSY
③ DECK SHEET
④ RING SEAL
⑤ TANK BOTTOM
⑥ PRODUCT

c. Roof leg assembly[7]

Figure 3-10. Internal floating roof deck fittings.


CURVATURE OF FLARED FITTINGS PRECLUDES THE POSSIBILITY OF SAMPLE BOTTLES SNAGGING OR CATCHING ON THE SAMPLE WELL.
BOLTING FLANGES TOP AND BOTTOM
DECK SKIN
10" (254 mm) DIA. PIPE
DIAPHRAM WITH 8 RADIAL SLITS FOR SAMPLING OR GAGING
LIQUID SURFACE

d. Sample well assembly[10]


LEG ASSEMBLY
GASKET
DECK SHEET
GIRDER ASSEMBLY
LEG GUIDE ASSEMBLY
LEG SLEEVE ASSEMBLY
LEG BEARING PAD ASSEMBLY
TANK BOTTOM
COVER
DECK SHEET
FLOAT WELL CROSS GIRDER
FLOAT WELL
FLOAT GUIDE
EXISTING GAUGE TAPE AND FLOAT
FLOAT STOP

f. Automatic gauge float well assembly[7]

e. Pressure/vacuum breaker assembly[7]

Figure 3-10. Internal floating roof deck fittings (Continued).

including sliding covers and fabric sleeves, which must accommodate the movements of the deck relative to the column as the liquid levels change.[6] A sliding cover rests on the upper rim of the column well (which is normally fixed to the roof) and bridges the gap or space between the column well and the column. The cover, which has a cutout or opening around the column, slides in a vertical direction relative to the column as the roof raises and lowers. At the same time, the cover slides in a horizontal direction relative to the rim of the well, which is fixed to the roof. A gasket around the rim of the well reduces emissions from this fitting. A flexible fabric sleeve seal between the rim of the well and the column (with a cutout or opening to allow vertical motion of the seal relative to the columns) similarly accommodates limited horizontal motion of the roof relative to the column. A third design, which is proprietary, is depicted in Figure 3-10b. This design, in effect, combines the advantages of the flexible fabric sleeve seal with a well that excludes all but a small portion of the liquid surface from direct communication with the vapor space above the floating roof.

3.2.3.3 Roof Legs or Hanger Wells. To prevent damage to fittings underneath the deck and to allow for tank cleaning or repair, supports are provided to hold the deck a pre-determined distance off the tank bottom. These supports consist of adjustable or fixed legs attached to the floating deck or hangers suspended from the fixed roof. For adjustable legs or hangers, the load-carrying element passes through a well or sleeve in the deck. With noncontact decks, the well should extend into the liquid stock.[6] Figure 3-10c depicts a roof leg assembly.

3.2.3.4 Sample Pipes or Wells. A sample well may be provided to allow for sampling of the liquid stock. Typically, the well is funnel-shaped to allow for easy entry of a sample thief. A closure is provided, which is typically located at the lower end of the funnel and which frequently consists of a horizontal piece of fabric slit radially to allow thief entry. The well should extend into the liquid stock on noncontact decks.[6] Figure 3-10d depicts a sample well assembly.

Alternately, a sample well may consist of a slotted pipe extending into the liquid stock, equipped with an ungasketed or gasketed sliding cover.[6]

3.2.3.5 Vacuum Breakers. When the internal floating deck is either being landed on its legs or floated off its legs, a vacuum breaker is used to equalize the pressure of the vapor space across the deck. This is accomplished by opening a deck penetration that usually consists of a well formed of pipe or framing on which rests a cover. To the underside of the cover is attached a guided leg of such length that it contacts the tank bottom as the internal floating deck approaches the tank bottom. When in contact with the tank bottom, the guided leg mechanically opens the breaker by lifting the cover off the well. When the leg is not contacting the bottom, the penetration is closed by the cover resting on the well. The closure may be with or without a gasket between the cover and neck. Since the purpose of the vacuum breaker is to allow the free exchange of air and/or vapor, the well does not extend appreciably below the deck.[6] Figure 3-10e depicts a pressure vacuum assembly. The gasket on the underside of the cover, or conversely on the upper rim of the well, provides a small measure of emission control (~20 percent emissions reduction) during periods when the roof is free floating and the breaker is closed.

3.2.3.6 Automatic Gauge Float Wells. Gauge floats are used to indicate the level of stock within the tank. They usually consist of a float residing within a well that passes through the floating deck. The float is connected to an indicator on the exterior of the tank via a tape passing through a guide system on the fixed roof. The float rests on the stock surface within the well. The well is closed by a cover that rests on the well. Evaporation loss can be reduced by gasketing and/or bolting the connection between the cover and the rim of the well. The cable passes through a bushing located at the center of the cover. As with other similar deck penetrations, the well extends into the liquid stock on noncontact floating decks.[6] Figure 3-10f depicts a bolted automatic gauge float well assembly.

3.2.3.7 Ladder Wells. Some tanks are equipped with internal ladders that extend from a manhole in the fixed roof to the tank bottom. The deck opening through which the ladder passes is constructed with similar design details and considerations as those for column wells, as discussed in Section 3.2.3.2.[6]

3.2.4 Storage Tank Emissions and Emission Equations

3.2.4.1 Fixed-Roof Tank Emissions. The major types of emissions from fixed-roof tanks are breathing and working losses. Breathing loss is the expulsion of vapor from a tank vapor space that has expanded or contracted because of daily changes in temperature and barometric pressure. The emissions occur in the absence of any liquid level change in the tank.

Filling losses are associated with an increase of the liquid level in the tank. The vapors are expelled from the tank when the pressure inside the tank exceeds the relief pressure as a result of filling. Emptying losses occur when the air that is drawn into the tank during liquid removal saturates with hydrocarbon vapor and expands, thus exceeding the fixed capacity of the vapor space and overflowing through the pressure vacuum valve. Combined filling and emptying losses are called "working losses."

Emission equations for breathing and working losses were developed for EPA Publication No. AP-42.[11] The equations used in estimating emissions rates for fixed roof tanks storing VOL are:

$$L_T = L_B + L_W \qquad (3\text{-}1)$$

$$L_B = 1.02 \times 10^{-5} M_v \left(\frac{P}{14.7-P}\right)^{0.68} D^{1.73} H^{0.51} T^{0.5} F_p C K_c \qquad (3\text{-}2)$$

$$L_W = 1.09 \times 10^{-8} M_v P V N K_n K_c \qquad (3\text{-}3)$$

where, L_T = total loss (Mg/yr)
L_B = breathing loss (Mg/yr)
L_W = working loss (Mg/yr)
M_v = molecular weight of product vapor (lb/lb mole); 80 assumed as a typical value for VOL liquids
P = true vapor pressure of product (psia)
D = tank diameter (ft)
H = average vapor space height (ft): use tank specific values or an assumed value of one-half the tank height
T = average diurnal temperature change in °F; 20°F assumed as a typical value

F_p = paint factor (dimensionless); 1.0 for clean white paint

C = tank diameter factor (dimensionless):

for diameter ≥ 30 feet, $C = 1$

for diameter < 30 feet,

$$C = 0.0771\,D - 0.0013(D^2) - 0.1334$$

K_c = product factor (dimensionless) = 1.0 for VOL

V = tank capacity (gal)

N = number of turnovers per year (dimensionless)

K_n = turnover factor (dimensionless):

for turnovers > 36, $K_n = \frac{180 + N}{6N}$

for turnovers ≤ 36, $K_n = 1$

3.2.4.2 External Floating-Roof Tank Emissions. Standing-storage losses, which result from causes other than a change in the liquid level, constitute the major source of emissions from external floating roof tanks. The largest potential source of these losses is an improper fit between the seal and the tank shell (seal losses). As a result, some liquid surface is exposed to the atmosphere. Air flowing over the tank creates pressure differentials around the floating roof. Air flows into the annular vapor space on the leeward side and an air-vapor mixture flows out on the windward side.

Withdrawal loss is another source of emissions from floating roof tanks. When liquid is withdrawn from a tank, the floating roof is lowered, and a wet portion of the tank wall is exposed. Withdrawal loss is the vaporization of liquid from the wet tank wall.

VOL emissions from external floating roof tanks are estimated using equations based on a pilot tank study conducted for the EPA by the Chicago Bridge and Iron Company.[8] Appendix C describes the development of the emission equations and the associated emission factors.

From the equations presented below, it is possible to estimate the total evaporation loss for external floating roof tanks, L_T, which is the sum of the withdrawal loss, L_W, and the external floating roof seal loss, L_{SE}. These equations in large part are extracted from AP-42.[11] However, minor changes have been made to update the equations. (Note: external floating roof tanks have no appreciable losses from fittings.)

$$L_T = L_W + L_{SE} \qquad (3\text{-}4)$$

$$L_W = 4.28 \times 10^{-4}\ QCW_L/D \qquad (3\text{-}5)$$

$$L_{SE} = K_S V^N P^* D M_V\ K_C/2205 \qquad (3\text{-}6)$$

where, L_T = total loss (Mg/yr)

L_W = withdrawal loss (Mg/yr)

L_{SE} = seal loss from external floating roof tanks (Mg/yr)

Q = product average throughput (bbl/yr); tank capacity (bbl/turnover) x turnovers/yr

C = product withdrawal shell clingage factor (bbl/10^3 ft^2); use 0.0015 bbl/10^3 ft^2 for VOL in a welded steel tank with light rust (0.0075 for dense rust)

W_L = density of product (lb/gal); 7.4 to 8.0 lb/gal assumed as typical range for VOL liquids

D = tank diameter (ft)

K_S = seal factor: obtain from Table 3-4

V = average windspeed for the tank site (mph); 10 mph assumed average windspeed

N = seal windspeed exponent (dimensionless): obtain from Table 3-4

P^* = the vapor pressure function (dimensionless);
$P^* = 0.068P/((1 + (1 - 0.068P)^{0.5})^2)$
P = the true vapor pressure of the materials stored (psia)

M_V = molecular weight of product vapor (lb/lbmole)

K_C = product factor (dimensionless) = 1.0 for VOL

3.2.4.3 Internal Floating Roof Tank Emissions. As ambient wind flows over the exterior of an internal floating roof tank, air flows into the enclosed space between the fixed and floating roofs through some of the shell vents and out of the enclosed space through others. Any VOC vapors that have evaporated from exposed liquid surface and that have not been contained by the floating deck will be swept out of the enclosed space.

Losses of VOC vapors from under the floating roof occur in one of four ways:

(1) through the annular rim space around the perimeter of the floating roof (rim or seal losses);

(2) through the openings in the deck required for various types of fittings (fitting losses);

Table 3-4. SEAL RELATED FACTORS FOR EXTERNAL FLOATING ROOF TANKS[a]

Seal type	$(K_S)^b$	$(N)^c$
Metallic shoe seal		
Primary seal only	1.2	1.5
With shoe mounted secondary seal	0.8	1.2
With rim mounted secondary seal	0.2	1.0
Liquid mounted resilient seal		
Primary seal only	1.1	1.0
With weather shield	0.8	0.9
With rim mounted secondary seal	0.7	0.4
Vapor mounted resilient seal		
Primary seal only	1.2	2.3
With weather shield	0.9	2.2
With rim mounted secondary seal	0.2	2.6

[a] Based on emissions from tank seal system with emissions control devices (roof, seals, etc.) in reasonably good working condition, no visible holes, tears or unusually large gaps between the seals and the tank wall.

[b] K_S = seal factor in Equation 3-6.

[c] N = seal windspeed exponent (dimensionless) in Equation 3-6.

(3) through the nonwelded seams formed when joining sections of the deck material (deck seam losses); and

(4) through evaporation of liquid left on the tank wall following withdrawal of liquid from the tank (withdrawal loss).

The withdrawal loss from an internal floating roof tank is similar to that discussed in the previous section for external floating roofs. The other losses, seal losses, fitting losses and deck seam losses, occur not only during the working operations of the tank but also during free standing periods. The mechanisms and loss rates of internal floating roof tanks was studied in detail by the Chicago Bridge and Iron Company for the American Petroleum Institute.[6] The results of this work form the basis for internal floating roof emissions discussion.

Several potential mechanisms for vapor loss from the rim seal area of an internal floating roof tank can be postulated:

- circumferential vapor movement underneath vapor-mounted rim seals;
- vertical mixing, due to diffusion or air turbulence, of the vapor in gaps that may exist between any type of rim seal and the tank shell;
- expansion of vapor spaces in the rim area due to temperature or pressure changes;
- varying solubility of gases, such as air, in the rim space liquid due to temperature and pressure changes;
- wicking of the rim space liquid up the tank shell; and
- vapor permeation through the sealing material.

For external floating roof tanks, wind-generated air movement across the roof is the dominant factor affecting rim seal loss. In comparison, for freely-vented internal floating roof tanks, in which the air movement is significantly reduced, no clearly dominant loss mechanism can be discerned.[6]

Vapor permeability is the only potential rim seal area loss mechanism that is readily amenable to independent investigation. Seal fabrics are generally reported to have very low permeability to typical hydrocarbon vapors, such that this source of loss is not considered to be significant. However, if a seal material is used that is highly permeable to the vapor from the stored stock, the rim seal loss could be significantly higher than that estimated from the rim seal loss equation presented later in this section.[6] Particularly when dealing with VOL rather than petroleum liquids, attention must be paid to the properties of the individual compounds being stored. For instance, benzene is suspected of having permeability losses that equal or exceed convective and diffusion losses from the seal.[13] Additional permeability data for VOL/seal material combinations must be developed to fully characterize the significance of permeability losses. Permeability is discussed in more detail in Appendix C.

The extent to which any or all of these mechanisms contributes to the total fitting loss is not known. The relative importance of the various mechanisms probably depends on the type of fitting, the design of the fitting seal, and whether or not the deck is in contact with the stored liquid.[6]

Floating decks are typically made by joining several sections of deck material together, resulting in seams in the deck. To the extent that these seams are not completely vapor tight, they become a source of loss. Generally the same loss mechanisms discussed for deck fittings may apply to deck seams.[6]

Emissions from internal floating roof tanks can be estimated from the following equations[6]: (Note that these equations apply only to freely vented internal floating roof tanks.)

$$L_T = L_w + L_r + L_f + L_d \qquad (3\text{-}7)$$

where:

L_T = the total loss (Mg/yr)

$$L_w = \frac{(0.943)\ Q\ C\ W_l}{D}\left[1 + \left(\frac{N_c\ F_c}{D}\right)\right]/2205$$

where D = tank diameter (ft)

N_c = number of columns (dimensionless)

F_c = effective column diameter (ft); 1.0 assumed

L_r = the rim seal loss (Mg/yr) = $(K_r D)\ P^*\ M_v\ K_C/2205$

L_f = the fitting loss (Mg/yr) = $(F_f)\ P^*\ M_v\ K_C/2205$

L_d = the deck seam loss (Mg/yr) = $(F_d\ K_d\ D^2)\ P^*\ M_v\ K_C/2205$

K_r = the rim seal loss factor (lb mole/ft yr) that for an average fitting seal is as follows:

Seal system description	K_r (lb mole/ft yr)
Vapor-mounted primary seal only	6.7
Liquid-mounted primary seal only	3.0
Vapor-mounted primary seal plus secondary seal	2.5
Liquid-mounted primary seal plus secondary seal	1.6

D = the tank diameter (ft)

P^* = the vapor pressure function (dimensionless)

$$P^* = 0.068\ P/((1 + (1 - 0.068\ P)^{0.5})^2)$$

P = the true vapor pressure of the material stored (psia)

M_v = the average molecular weight of the product vapor (lb/lbmole). A typical value for VOL liquids is 80 lb/lbmole.

K_C = the product factor (dimensionless) = 1.0 for VOL

2205 = constant (lb/Mg)

F_f = the total deck fitting loss factor (lbmole/yr)

$$= \sum_{i=1}^{n} (N_{f_i}\ K_{f_i}) = [(N_{f_1}\ K_{f_1}) + (N_{f_2}\ K_{f_2}) + \ldots + (N_{f_n}\ K_{f_n})]$$

where:

N_{f_i} = number of fittings of a particular type (dimensionless). N_{f_i} is determined for the specific tank or estimated from Tables 3-5 and 3-6

K_{f_i} = deck fitting loss factor for a particular type fitting (lbmole/yr). K_{f_i} is determined for each fitting type from Table 3-6

n = number of different types of fittings (dimensionless)

Table 3-5. TYPICAL NUMBER OF COLUMNS AS A FUNCTION OF TANK DIAMETERS[6]

Tank diameter range D (ft)	Typical number columns, N_c
$0 < D \leq 85$	1
$85 < D \leq 100$	6
$100 < D \leq 120$	7
$120 < D \leq 135$	8
$135 < D \leq 150$	9
$150 < D \leq 170$	16
$170 < D \leq 190$	19
$190 < D \leq 220$	22
$220 < D \leq 235$	31
$235 < D \leq 270$	37
$270 < D \leq 275$	43
$275 < D \leq 290$	49
$290 < D \leq 330$	61
$330 < D \leq 360$	71
$360 < D \leq 400$	81

Note: This table was derived from a survey of users and manufacturers. The actual number of columns in a particular tank may vary greatly depending on age, roof style, loading specifications, and manufacturing perogatives. This table should not supersede information based on actual tank data.

Table 3-6. SUMMARY OF DECK FITTING LOSS FACTORS (K_f) AND TYPICAL NUMBER OF FITTINGS (N_f)[6]

Deck fitting type	Deck fitting loss factor, K_f (lbmole/yr)	Typical number of fittings, (N_f)
1. Access Hatch		1
a. Bolted cover, gasketed	1.6	
b. Unbolted cover, gasketed	11	
c. Unbolted cover, ungasketed	25	
2. Automatic Gauge Float Well		1
a. Bolted cover, gasketed	5.1	
b. Unbolted cover, gasketed	15	
c. Unbolted cover, ungasketed	28	
3. Column Well		(see Table 3-5)
a. Built-up column-sliding cover, gasketed	33	
b. Built-up column-sliding cover, ungasketed	47	
c. Pipe column-flexible fabric sleeve seal	10	
d. Pipe column-sliding cover, gasketed	19	
e. Pipe column-sliding cover, ungasketed	32	
4. Ladder Well		1
a. Sliding cover, gasketed	56	
b. Sliding cover, ungasketed	76	
5. Roof Leg or Hanger Well		$(5 + \frac{D}{10} + \frac{D^2}{600})$**
a. Adjustable	7.9	
b. Fixed	0	
6. Sample Pipe or Well		1
a. Slotted pipe-sliding cover, gasketed	44	
b. Slotted pipe-sliding cover, ungasketed	57	
c. Sample well-slit fabric seal, 10% open area	12	
7. Stub Drain*, 1-inch diameter	1.2	$(\frac{D^2}{125})$**
8. Vacuum Breaker		1
a. Weighted mechanical actuation, gasketed	0.7	
b. Weighted mechanical actuation, ungasketed	0.9	

* Not used on welded, contact internal floating decks.

** D = tank diameter (ft).

F_d = the deck seam length factor (ft/ft^2)

= 0.15, for a deck constructed from continuous metal sheets with a 7 ft spacing between seams

= 0.33, for a deck constructed from rectangular panels 5 ft by 7.5 ft

= 0.20, an approximate value for use when no construction details are known

K_d = the deck seam loss factor (lbmole/ft yr)

= 0.34 for non-welded roofs

= 0 for welded decks

3.3 BASELINE CONTROL AND EMISSIONS ESTIMATES

The baseline control level is set by state regulations that affect VOL storage vessels. The control requirements are set forth in the State implementation plans (SIP). A typical SIP requires tanks with capacities greater than 40,000 gallons (≅150 m^3) storing material with vapor pressures greater than 1.5 psia (≅10.5 kPa), but less than 11 psia (≅76.6 kPa), to have a floating roof. For this group of tanks, baseline control is assumed to be the noncontact internal floating roof with a vapor-mounted primary seal, because it is the least costly means of complying with the SIPs. A typical SIP requires tanks with capacities greater than 40,000 gallons (≅150 m^3) storing liquids with vapor pressures greater than 11 psia (≅76.6 kPa) to either have vapor recovery systems or to be constructed as high pressure vessels. Therefore, vapor recovery is assumed to be the baseline control for this group of tanks.

Texas contains an estimated 35 percent of the total national VOL tank population and has an atypical SIP. Texas requires tanks with capacities greater than 25,000 gallons (≅95 m^3) storing VOL with a vapor pressure greater than 0.5 psia (≅3.5 kPa) but less than 11 psia (≅76.6 kPa) to have a floating roof. Tanks with capacities greater than 25,000 gallons (≅95 m^3) storing VOL with vapor pressures greater than 11 psia (276 kPa) must have a vapor recovery system. Texas contains such a significant portion of the tank population that this difference in cutoff size must be considered in the baseline control level. Therefore, in addition to the floating roofs in all tanks with capacities greater than 40,000 gallons (≅150 m^3) and storing VOL with vapor pressures between 1.5 and 11 psia (≅10.5 and 76.6 kPa), it is assumed that 35 percent of the tanks with capacities between 25,000 gallons and 40,000 gallons (≅95 m^3 to 150 m^3) storing VOL with vapor pressures between 0.5 psia and 11.5 psia (≅3.5 to 76 kPa) will be constructed with noncontact internal floating roofs with vapor-mounted primary seals in the absence of a standard of performance. It is further assumed that 35 percent of the tanks that have capacities between 25,000 gallons and 40,000 gallons (≅95 m^3 and 150 m^3) storing VOL with vapor pressures greater than 11 psia (≅76.6 kPa), will be constructed with vapor recovery systems or stored in pressure vessels. This is in addition to the vapor recovery systems or pressure vessels for all tanks greater than 40,000 gallons (≅150 m^3) and storing VOL with vapor pressures exceeding 11 psia (76.6 kPa).

The remaining 65 percent of the tanks that have capacities between 25,000 gallons (≅95 m^3) and 40,000 gallons (≅150 m^3) and storing materials with vapor pressures between 0.5 and 1.5 psia (≅3.5 and 10.5 kPa) are assumed to be uncontrolled, fixed-roof tanks. It is assumed that every tank smaller than 25,000 gallons (≅95 m^3) and every tank storing material with a vapor pressure less than 0.5 psia (≅3.5 kPa) will be constructed as an uncontrolled, fixed-roof tank. Figure 3-11 summarizes the baseline control assumptions.

The total VOC emission rate from VOL storage vessels is estimated to be 37,800 Mg/yr based on the 1977 tank population described in Section 3.1 and the baseline control levels. This estimate assumes that currently existing or developing state regulations are fully implemented on the 1977 tank population. Included in this emissions total are an estimated 34,000 Mg/yr of VOC emitted from fixed roof tanks and an estimated 3,800 Mg/yr of VOC from floating roof tanks. The 37,800 Mg/yr emissions total is broken down among the three vapor-pressure/tank-size

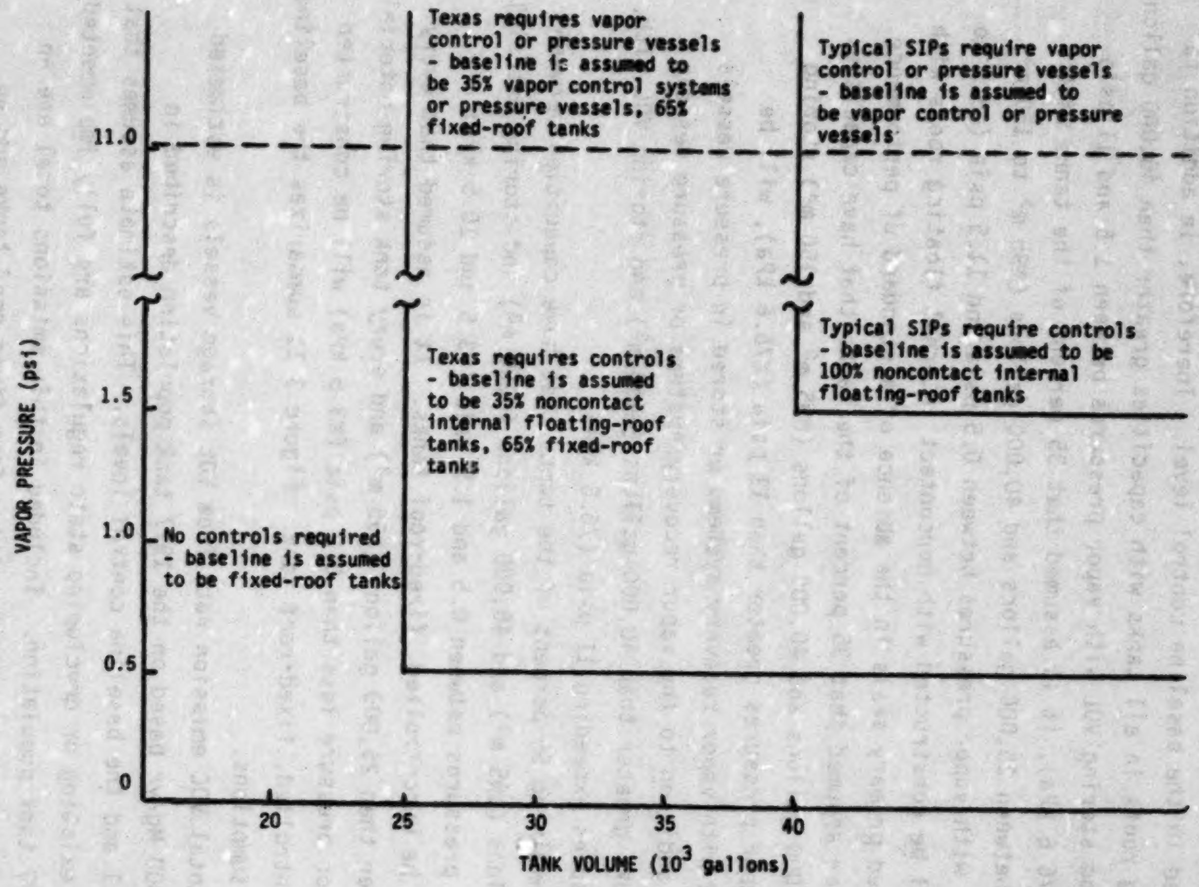
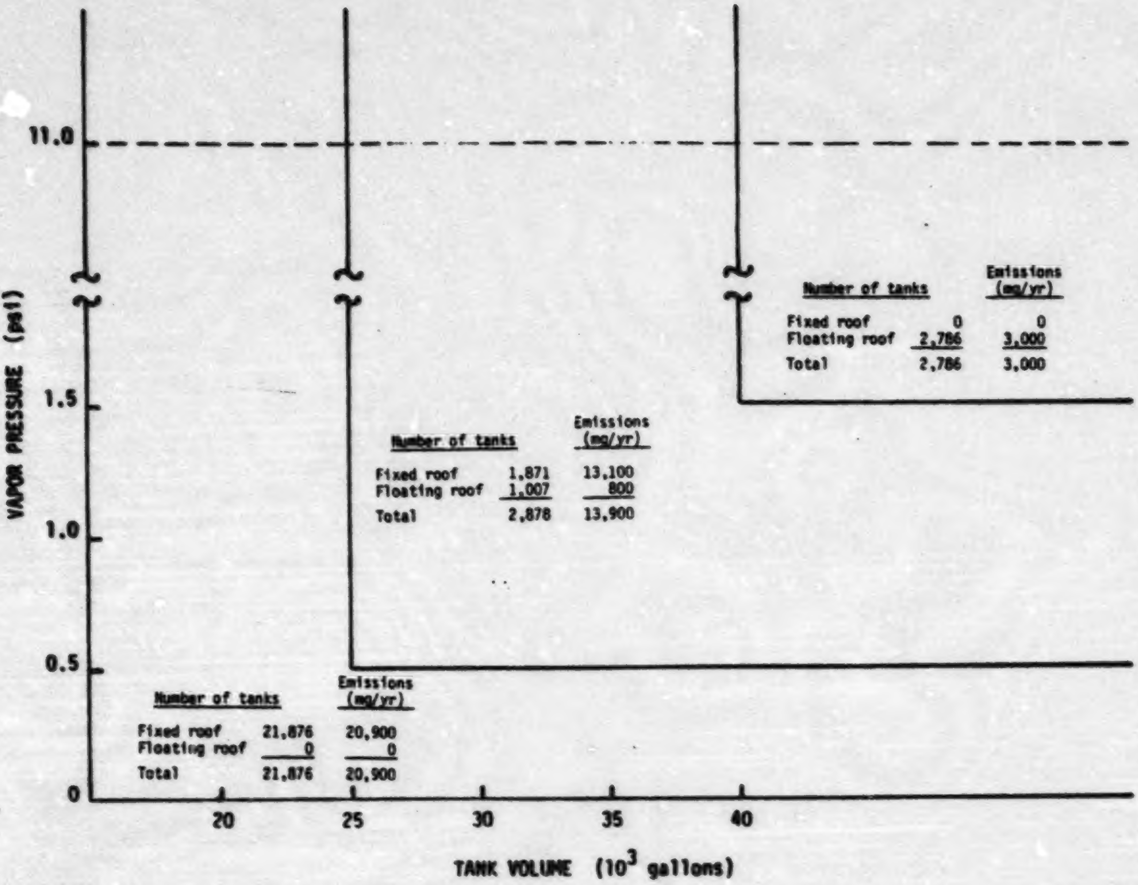


Figure 3-11. Baseline control summary.

regions that comprise the baseline control level scenario in Figure 3-12. Note that the number of tanks storing liquids with vapor pressures greater than 58.7 kPa (8.5 psia) is less than 1 percent of the tank population. These tanks have very little effect on the estimated number of tanks and emissions listed in Figure 3-12.



	Number of tanks	Emissions (mg/yr)
Fixed roof	0	0
Floating roof	2,786	3,000
Total	2,786	3,000

	Number of tanks	Emissions (mg/yr)
Fixed roof	1,871	13,100
Floating roof	1,007	800
Total	2,878	13,900

	Number of tanks	Emissions (mg/yr)
Fixed roof	21,876	20,900
Floating roof	0	0
Total	21,876	20,900

Figure 3-12. Baseline emissions totals (mg/yr; 1977 tank population) and numbers of tanks by vapor pressure/tank size region.

3.4 REFERENCES

1. Erickson, D. G. *Emission Control Options for the Synthetic Organic Manufacturing Industry*; (Unpublished draft submitted in fulfillment of EPA Contract No. 68-02-2577). Hydroscience, Inc. Knoxville, Tennessee. October 1978. 97 p.

2. Radian, Inc. *The Revised Organic Chemical Producers Data Base System, Final Interim Report*; (Submitted in fulfillment of EPA Contract No. 68-03-2623.) Austin, Texas. March 1979.

3. Booz, Allen, and Hamilton, Foster D. Snell Division. *Cost of Hydrocarbon Emissions Control to the U.S. Chemical Industry (SIC 28)*. Manufacturing Chemists Association. Florham Park, New Jersey. December 1977.

4. Memorandum from Rockstroh, M. A., TRW to Moody, W. T., TRW. February 1, 1980.

5. International Liquid Terminals Association. *Bulk Liquid Terminals and Storage Facilities, 1979 Directory*. Washington, D.C. 1979. 85 p.

6. The American Petroleum Institute (API) Draft Document, *Evaporation Loss from Internal Floating Roof Tanks*. API Publication 2519. Third Edition. 1982.

7. RFI Services Corporation. The Woodlands, Texas. Figures extracted from promotional literature with the permission of the company.

8. U.S. Environmental Protection Agency. *Measurements of Benzene Emissions from a Floating-Roof Test Tank*. Report No. EPA-450/3-79-020. Research Triangle Park, North Carolina. June 1979.

9. Brown Boiler and Tank Works, Ltd. Franklin, Pennsylvania. Figure extracted from promotional literature with the permission of the company.

10. Ultraflote Corporation. Houston, Texas. Figure extracted from promotional literature with the permission of the company.

11. U.S. Environmental Protection Agency. *Compilation of Air Pollution Emission Factors*. Report No. AP-42; Supplement 12, Research Triangle Park, North Carolina. April 1981.

12. TRW Environmental Division, Background Documentation for Storage of Organic Liquids. EPA Contract No. 68-02-3174. Research Triangle Park, N.C. May 1981.

13. U.S. Environmental Protection Agency, Draft Volume II Background Information Document for Benzene Storage Hazardous Air Pollutant Standards, EPA 450/______, January 1983.

4. CONTROL TECHNIQUES

This section describes the control techniques applicable to emissions of volatile organic compounds (VOC) from the storage of volatile organic liquids (VOL). It should be recognized that the emission sources in this industry are "un-traditional" in the sense that they do not have exhaust streams that normally are controlled by add-on control devices. Consequently, the evaluation of control techniques is not a straight-forward process of identification, testing and direct comparison of a series of add-on devices. Rather, it is the comparison of alternative tank types and equipment options that can be selected for use in storing VOL.

4.1 OVERVIEW

As discussed in Chapter 3, there are three major types of vessels used to store VOL: fixed roof tanks, internal floating roof tanks, and external floating roof tanks. In addition, optional equipment designs exist within each major tank type (e.g. seal design, roof fabrication fittings closure). Each tank type and equipment option has its own associated emissions rate. In effect, there is a spectrum of equipment options, with a corresponding spectrum of emission rates. The control techniques to be evaluated are these alternative storage vessel equipment types.

The major equipment options that affect emissions from the storage of VOL include:

- the tank type: fixed roof, internal floating roof, or external floating roof;
- the floating roof deck type: welded or bolted (pertinent to internal floating roof tanks only);

- the floating roof primary seal location: liquid- or vapor-mounted (pertinent to internal and external floating roof tanks);
- the types of deck fittings: controlled or uncontrolled (pertinent to internal floating roof tanks only);
- the floating roof seal system: primary seals only or primary and secondary seals (pertinent to internal and external floating roof tanks); and
- the use of add-on vapor control techniques: incinerators, adsorbers, or refrigerated condensers (pertinent to fixed roof tanks only).

Considering the optional types of equipment that can be used to store VOL, a hierarchy of equipment alternatives can be developed based on emission rate. This hierarchy, in order of decreasing emission rates, is listed in Table 4-1. The types of storage vessel equipment listed in Table 4-1 are described in detail in Chapter 3. Chapter 3 also outlines equations for estimating the emission rate for each of the major tank types and the equipment options that are available. These equations and the test data used to develop the equations (discussed in Appendix C) form the basis for evaluating the effectiveness of the control techniques discussed in this chapter.

The hierarchy of equipment options presented in Table 4-1 suggests that the emission rate of each control option relative to the others remains constant over all situations that may be found in the VOL storage industry. This is the case among the internal floating roof tanks, fixed roof tanks, and external floating roof tanks with liquid-mounted primary and secondary seals (Options 1, 3-7, and 9 in Table 4-1). For the most part, the relationship also holds true over the range of conditions (e.g. vapor pressure, number of turnovers, etc.) commonly found in the industry for the vapor recovery or control and for the external floating roof tank, vapor-mounted primary and secondary seal (Options 2 and 8 in Table 4-1). The ranking of these two options, however, does vary with the tank size and the vapor pressure of the material stored. To illustrate the relative emission rates of the equipment options, the total emission rates for each option for a range of tank sizes (100 to 10,000 m^3) has

Table 4-1. HIERARCHY OF EQUIPMENT TYPES BASED ON EMISSIONS RATE[a]

Control Option	Equipment description	Abbreviated notation
1	Fixed roof tank (baseline)	Fixed roof tank
2[b]	External floating roof tank, vapor-mounted primary and secondary seals	$EFR_{vm,ss}$
3	Internal floating roof tank, bolted construction (contact or noncontact), vapor-mounted primary seal only, with uncontrolled deck fittings	${}_{b}IFR_{vm}$
4	Internal floating roof tank, bolted construction (contact or noncontact), liquid-mounted primary seal only, with uncontrolled deck fittings	${}_{b}IFR_{lm}$
5	Internal floating roof tank, bolted construction (contact or noncontact), liquid-mounted primary seal only, with controlled deck fittings	${}_{b}IFR_{lm,cf}$
6	Internal floating roof tank, bolted construction (contact or noncontact), liquid-mounted primary and secondary seals, with controlled deck fittings	${}_{b}IFR_{lm,cf,ss}$
7	Internal floating roof tank, welded construction (steel pan or FRP deck), liquid-mounted primary and secondary seals, with controlled deck fittings	${}_{w}IFR_{lm,cf,ss}$
8[b]	Fixed roof tank with thermal oxidation, carbon adsorption or refrigerated condenser add-on vapor recovery equipment	Vapor recovery or control
9	External floating roof tank, deck types are welded construction, liquid-mounted primary and secondary seals, controlled deck fittings are not applicable	$EFR_{lm,ss}$

---

[a] Listed in order of decreasing emission rates; Control Option 1 possessing the largest emission rate and Control Option 9 possessing the smallest emission rate.

[b] The rank based on emissions rate for this option varies depending on the specific parameters (e.g., number of turnovers, tank size) of the tank being considered.

been calculated and plotted in Figures 4-1 and 4-2. Figures 4-1 and 4-2 are for tanks with 50 and 10 turnovers per year, respectively. The plotted emission rates are for a stored VOL with a vapor pressure (in liquid and condensed vapor phase) of 34.5 kPa (5 psia). (See Figures 4-1 and 4-2.)

Apart from the intrinsic emission-affecting characteristics of each tank type and equipment option, the emission rate from all storage vessel types is affected by the vapor pressure of the material stored and the frequency of tank turnovers. The impact of the vapor pressure and the turnover rate on the emission rate, however, varies among the three major tank types. Consequently, the hierarchy of equipment-types, or the relative emission rates of the various equipment types, can be affected by these variables. Comparison of Figures 4-1 and 4-2 illustrates the effects of turnovers. The tank scenarios, for which emission rates are plotted, are identical in these figures except for the turnover rate. Figure 4-1 is for tanks experiencing 50 turnovers per year and Figure 4-2 is for tanks experiencing 10 turnovers per year. It can be seen that decreasing the annual turnover rate from 50 to 10 decreases the emission rate for fixed roof tanks and fixed roof tanks with vapor recovery or control systems; conversely, the turnover rate has very little effect on internal and external floating roof tank emission rates: consequently, the higher the turnover rate, the larger the difference between fixed roof and floating roof tank emission rates. The rank or relative effectiveness of fixed roof tanks equipped with vapor recovery or control devices is adversely affected by an increase in the turnover rate (i.e., the relative effectiveness as a control technique decreases).

The effects that the vapor pressure of the stored VOL has on the relative emission rates of the equipment options are not illustrated by Figure 4-1. As the vapor pressure of the stored liquid increases, the emission rates from both fixed and floating roof tanks increase. However, the vapor pressure functions in the equations used to estimate losses from fixed and floating roof tanks differ, and, therefore, the percent increase in floating roof tank emissions is greater than the percent

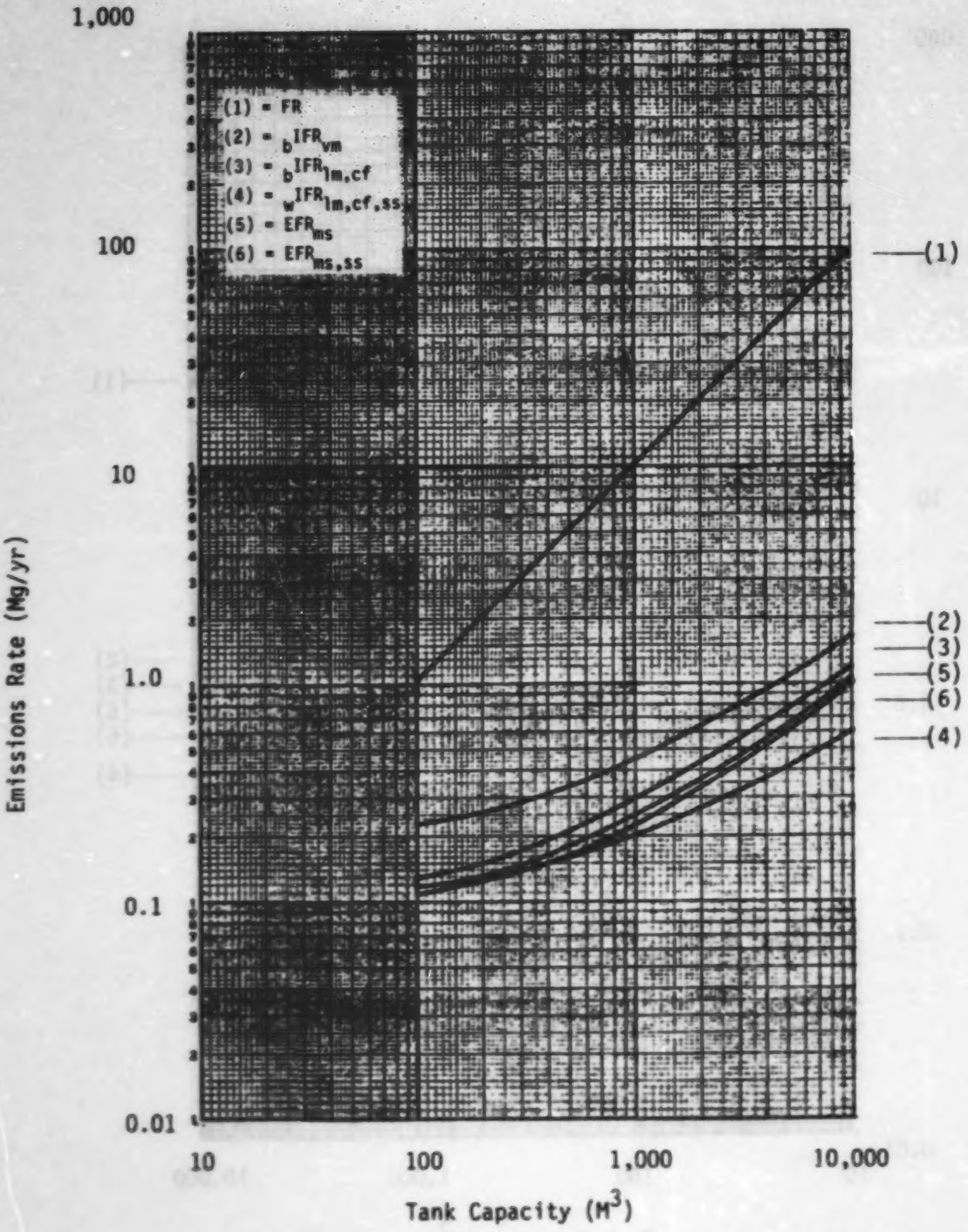


Figure 4-1. Emissions rates for alternative equipment types (50 turnovers per year; vapor pressure = 1.0 psia).

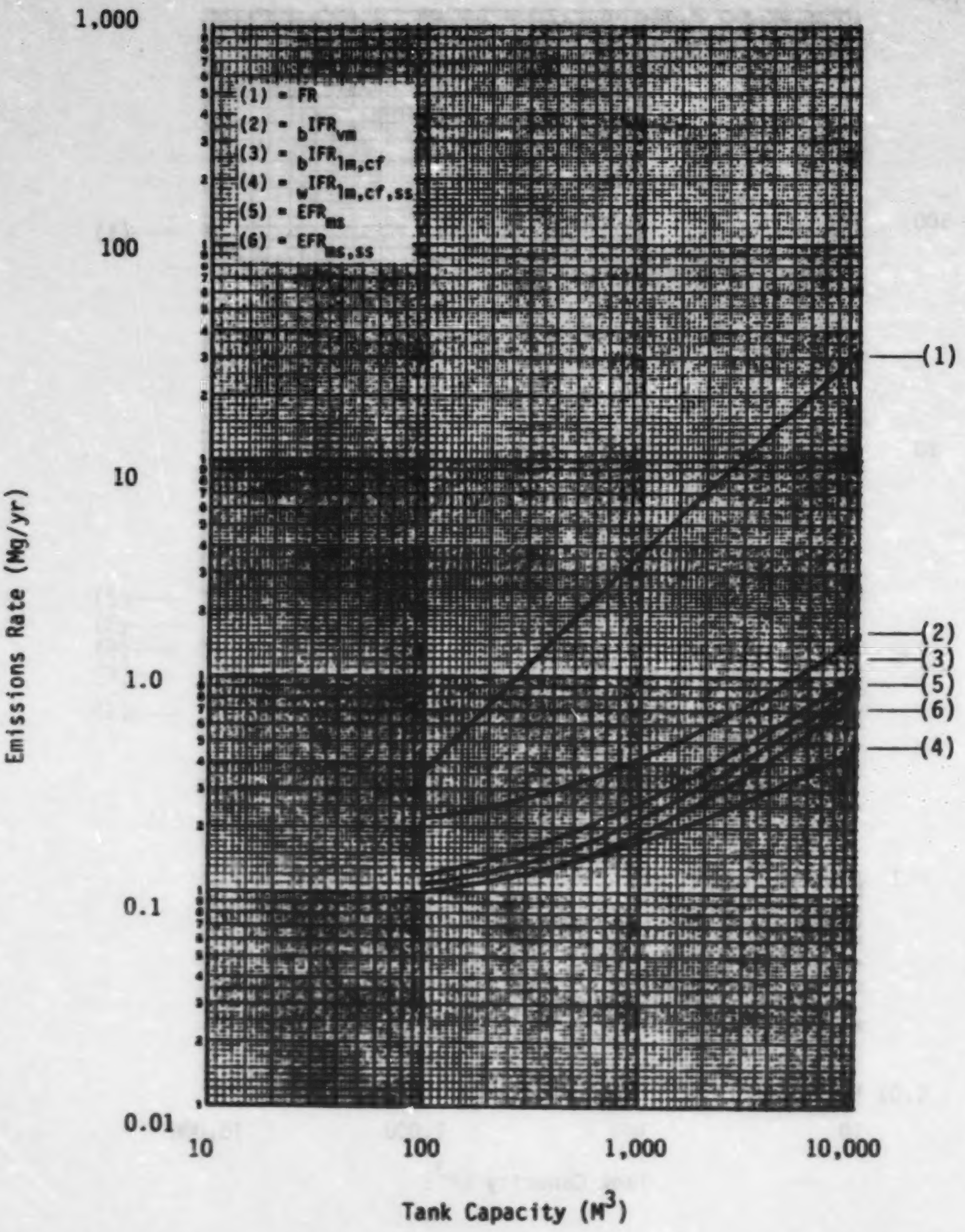


Figure 4-2. Emissions rates for alternative equipment types (10 turnovers per year; vapor pressure = 1.0 psia).

increase in fixed roof tank emissions for a similar increment in vapor pressure. (Note that this trend may reverse above 8.5 psia depending on the ratio of fixed roof tank breathing losses to working losses.) Consequently, an increase in vapor pressure decreases the difference between fixed and floating roof tank emission rates. This is opposite to the effect of the turnover rate. Within the range of conditions commonly found in VOL storage vessels, however, neither the effect of the vapor pressure nor the turnover rate changes the rank of the fixed roof tank and floating roof tank equipment options.

Because the emission rate from all types of tanks is affected by a number of tank variables (i.e., vapor pressure, tank size, turnovers, the nature of the VOL), a single model tank is used as a common basis for evaluating effectiveness. The model tank has the following characteristics:

- tank diameter - 9.1 m (30 ft);
- tank height - 9.1 m (30 ft);
- tank capacity - 606 m^3 (160,000 gallons);
- vapor pressure of the VOL stored - 6.9 kPa (1 psia);
- density of VOL stored - 7.4 lb/gallon;
- molecular weight of the product vapor - 80 lb/lbmole; and
- turnover rate - 50 per year.

The emissions associated with the model tank under each equipment option have been estimated with the equations presented in Chapter 3 and listed for comparison in Table 4-2. The significance of these emission estimates are discussed in the following sections.

4.2 FIXED ROOF TANKS

A fixed roof tank is the minimum acceptable equipment currently employed for the storage of VOL. The discussion of control techniques, therefore, will relate the effectiveness of alternative storage equipment types to the effectiveness of fixed roof tanks. Working and breathing losses normally incurred from the storage of VOL in fixed roof tanks can be reduced in any of the following ways:

(1) by the installation of an internal floating roof with rim seals;

Table 4-2. MODEL TANK EMISSION RATES FOR DIFFERENT EQUIPMENT OPTIONS[1] (Mg/yr)

Fixed roof tank		Internal floating roof tank						Internal and external floating roof tank	External floating roof tank	
Breathing Losses	Working Losses	Seal losses		Fitting losses		Deck losses		Working losses	Seal losses	
		Type	Emission	Case	Emission	Roof type	Emission		Type	Emission
0.88	5.34	Vapor-mounted	0.128	Uncontrolled[2]	0.21	Bolted	0.04	0.03	Vapor-mounted	4.59
		Liquid-mounted	0.058	Controlled[3]	0.11	Welded	0.0		Liquid-mounted	0.21
		Vapor-mounted with secondary	0.048						Vapor-mounted with secondary	1.52
		Liquid-mounted with secondary	0.031						Liquid-mounted with secondary	0.034
									Metallic shoe	0.727
									Metallic shoe with secondary	0.038

[1] Model tank parameters: 160,000 gallon capacity
30 feet in diameter; 30 feet in height
1 psia vapor pressure of the material stored
80 lbs/lbmole molecular weight of the product as liquid product and as condensed vapor
50 turnovers per year
7.4 lb/gallon density

[2] Uncontrolled assumes: (1) access hatch, with ungasketed, unbolted cover; (2) automatic gauge float well, with ungasketed, unbolted cover; (3) 1-built-up column well, with ungasketed sliding cover; (4) ladder well, with ungasketed sliding cover; (5) 10-adjustable roof legs; (6) 1-sample well with slit fabric seal (10% open area); (7) 7-one inch diameter stub drains; and (8) 1-vacuum breaker with gasketed weighted mechanical actuation.

[3] Controlled assumes: (1) 1-access hatch, with gasketed, bolted cover; (2) 1-automatic gauge float well, with gasketed, bolted cover; (3) 1-pipe column with flexible fabric sleeve seal; (4) 1-ladder well, with gasketed sliding cover; (5) 10-adjustable roof legs; (6) sample well with slit fabric seal (10% open area); (7) 7-one inch diameter stub drains; and (8) vacuum breaker, with gasketed weighted mechanical actuation.

(2) by the construction of an external floating roof tank with liquid-mounted primary and secondary seals in lieu of a fixed roof tank; and

(3) by the installation and use of a vapor recovery system (e.g., carbon adsorption or refrigerated condensation) or a vapor control system (e.g., incineration).

This list defines only the major types of control techniques applicable to the storage of VOL. Optional equipment designs that influence the effectiveness of minimizing VOL emissions exist within each major type of control technique. The following sections discuss the relative effectiveness of these equipment options.

4.3 INTERNAL FLOATING ROOF TANKS

Internal floating roof tanks with rim seal systems emit less VOC per unit of storage than fixed roof tanks. In new and replacement tank situations, internal floating roof tanks can be constructed in lieu of fixed roof tanks. In this sense they are a control technology for fixed roof tanks. Internal floating roofs also can be used directly as a control device for existing fixed roof tanks. This requires minor modifications to the tank shell (e.g., cutting roof vents).

Depending on the type of roof and seal system selected, an internal floating roof in the model fixed roof tank will reduce the emission rate by 93.4 to 97.3 percent. An internal floating roof, regardless of design, reduces the area of exposed liquid surface in the tank. Reducing the area of exposed liquid surface, in turn, decreases the evaporative losses. The largest emissions reduction available from the control options is achieved by the presence of the floating roof vapor barrier that precludes direct communication between a large portion of the liquid surface and the atmosphere. All internal floating roofs share this design benefit. The relative effectiveness of one internal floating roof design over another, therefore, is a function of how well the floating roof can be sealed.

From an emissions standpoint, the most basic internal floating roof design is the noncontact, bolted, aluminum, internal floating roof with a single vapor-mounted wiper seal. As discussed in Section 3.2.4.3, there are four types of losses from this roof design. These losses with an estimate of their respective percentage contributions to the total loss from the model tank are as follows:

(1)	rim or seal losses;	32%
(2)	fitting losses;	51%
(3)	deck seam losses; and	10%
(4)	withdrawal losses.	7%

With the exception of withdrawal losses, which are inherent in all internal floating roof designs, the losses listed above can be reduced by employing roofs with alternative design features. Table 4-3 lists alternative floating roof equipment designs and the model tank emission rate associated with each type of equipment. Table 4-3 is calculated from the emission estimates in Table 4-2 by adding the appropriate emission components for each case. The following sections elaborate on the alternative equipment that can be employed on internal floating roofs. The discussion is arranged according to the major emissions categories.

4.3.1 Controls for Fitting Losses

Fitting losses occur through the penetrations in an internal floating deck. Penetrations exist to accommodate the various types of fittings that are required for proper operation of an internal floating roof. Fitting losses can be controlled with gasketing and sealing techniques, or by the substitution of a lower emitting fitting type that serves the same purpose. Table 4-4 lists the fitting types that are pertinent to emissions and an abbreviated description of the equipment that is considered to be representative of "uncontrolled" fittings and "controlled" fittings. Certain fitting types are not amenable to control. These are not listed in Table 4-4. Section 3.2.3 provides a more detailed description of the various fitting types and the "control techniques" that can be applied.

The effectiveness of fitting "controls" at reducing the overall emission rate is a function of the number of fittings of each type that are employed on a given tank. On the model tank, which is representative of a typical medium sized tank, fitting "controls" reduce the total

Table 4-3. EFFECTIVENESS OF INTERNAL AND EXTERNAL FLOATING ROOF TANKS COMPARED TO A FIXED ROOF TANK FOR THE MODEL TANK[1]

	Internal or external floating roof tank			
Fixed roof tank	Case	Equipment type[2]	Total emission rate (Mg/yr)[3]	Reduction over fixed roof tank emission rate
Total emission rate 6.22 Mg/yr	1	${}_{b}\mathrm{IFR}_{vm}$	0.408	93.4%
(Working loss = 5.34) (Breathing loss = 0.88)	2	${}_{b}\mathrm{IFR}_{vm,cf}$	0.308	95.0%
	3	${}_{b}\mathrm{IFR}_{vm,cf,ss}$	0.228	96.3%
	4	${}_{b}\mathrm{IFR}_{lm}$	0.338	94.6%
	5	${}_{b}\mathrm{IFR}_{lm,cf}$	0.238	96.2%
	6	${}_{b}\mathrm{IFR}_{lm,cf,ss}$	0.211	96.6%
	7	${}_{w}\mathrm{IFR}_{lm,cf,ss}$	0.171	97.3%
	8	EFR^{4}_{vm}	4.62	25.7%
	9	$\mathrm{EFR}^{4}_{vm,ss}$	1.55	75.1%
	10	EFR^{4}_{lm}	0.24	96.1%
	11	$\mathrm{EFR}^{4}_{lm,ss}$	0.064	99.0%
	12	EFR^{4}_{ms}	0.76	87.8%
	13	$\mathrm{EFR}^{4}_{ms,ss}$	0.068	98.9%

---

[1] Model tank is 160,000 gallons capacity; 30 feet in diameter, 30 feet in height, 1 psia vapor pressure, 80 lb/lbmole molecular weight of product and condensed product vapor and 50 turnovers per year.

[2] Nomenclature explanation - ${}_{b}\mathrm{IFR}_{vm,cf,ss}$ - The subscript b or w indicates a bolted or welded roof deck; IFR indicates an internal floating roof type; EFR indicates an external floating roof tank type; the subscript vm, lm, or ms indicates a vapor-mounted, liquid-mounted or metallic shoe primary seal; the subscript cf indicates controlled fittings as described in the notes of Table 4-2; lack of the cf subscript indicates uncontrolled fittings; the subscript ss indicates a rim-mounted secondary seal; a lack of the ss subscript indicates that no secondary seal is employed.

[3] Sum of seal loss, fitting loss, deck loss and working loss from Table 4-2.

[4] External floating roofs are all welded construction and do not incur appreciable deck seam losses.

Table 4-4. "CONTROLLED" AND "UNCONTROLLED" INTERNAL FLOATING ROOF DECK FITTINGS

Deck fitting type	Equipment descriptions	
	Uncontrolled	Controlled
1. Access hatch	Unbolted, ungasketed cover*; or unbolted, gasketed cover	Bolted, gasketed cover
2. Automatic gauge float well	Unbolted, ungasketed cover*; or unbolted, gasketed cover	Bolted, gasketed cover
3. Column well	Built-up column-sliding cover, ungasketed*; built-up column-sliding cover, gasketed; pipe column-sliding cover, ungasketed; or pipe column-sliding cover, gasketed	Pipe column-flexible fabric sleeve seal
4. Ladder well	Ungasketed sliding cover*	Gasketed sliding cover
5. Sample pipe or well	Slotted pipe-sliding cover, ungasketed; or slotted pipe-sliding cover, gasketed	Sample well with slit fabric seal, 10% open area*
6. Vacuum breaker	Weighted mechanical actuation, ungasketed*	Weighted mechanical actuation, gasketed

*The fittings assumed in the uncontrolled case for estimating the effectiveness of fittings controls are marked with a single asterisk in the above table. This fittings scenario is representative of no single tank, but rather is the composite of what is estimated based on a survey of users and manufacturers to be typical of fittings on the majority of tanks currently in service. Note that the sample well with split fabric seal was used in the "uncontrolled" case for calculating emissions because it is in common use. It was also used in the "controlled" case because it is the lowest emitting fitting type.

fitting loss by about 48 percent. Since fitting losses are about 51 percent of the total internal floating roof tank loss (i.e., for an IFR_{vm} case), the fitting "controls" reduce the overall internal floating roof tank emission rate by about 25 percent over the IFR_{vm} without fitting controls. The additional emission reduction obtained by controlling fitting emissions increases the control efficiency of the IFR from 93.4 percent to 95.0 percent over a fixed roof tank as the base case.

4.3.2 Controls for Seal Losses

Internal floating roof seal losses can be minimized in either of two ways or their combination:

(1) by employing liquid-mounted primary seals instead of vapor-mounted seals;

(2) by employing secondary wiper seals in addition to primary seals.

All seal systems should be designed, installed and maintained to minimize the gap between the seals and the tank shell. The test data discussed in Appendix C support the general conclusion that seal losses increase rapidly when the seal gap exceeds 63.5 square centimeters per meter of tank diameter (3 in^2/ft diameter). Below this level, the effect of seal gap on seal loss is much less pronounced.

The effectiveness of alternate internal floating roof seal systems can be evaluated through inspection of the rim seal loss factors (K_r) that have been developed based on test data (summarized in Appendix C) for estimating losses for various seal systems. These factors are listed in Table 4-5. (Note these factors are for seals with average gaps.) Also listed in Table 4-5 are control efficiency and incremental control efficiency estimates. The control efficiency estimates (column 3 in Table 4-5) indicate the effectiveness of the various seal systems at reducing emissions over the level achieved by a vapor-mounted primary seal. (Note that the vapor-mounted primary seal is assumed to be the baseline control level to provide a common basis of comparison.) The incremental control efficiency estimates (column 4 in Table 4-5) demonstrate the effectiveness of each seal system relative to the next less stringent seal system (i.e., the next higher emitting seal system). These efficiencies are calculated directly from the K_r values.

Table 4-5. INTERNAL FLOATING ROOF RIM SEAL SYSTEMS SEAL LOSS FACTORS AND CONTROL EFFICIENCIES

Seal system	K_r (lb-mole/ft-yr)	Seal loss control efficiency related to baseline	Incremental control efficiency
Vapor-mounted primary seal only	6.7	IFR baseline (0%)	—
Liquid-mounted primary seal only	3.0	55%	55%
Vapor-mounted primary and secondary seals	2.5	63%	17%
Liquid-mounted primary and seconadary seals	1.6	76%	36%

Application of a liquid-mounted primary and secondary seal system in place of a vapor-mounted primary seal would reduce seal losses an estimated 76 percent. On the model tank, where these seal losses represent roughly one-third of the total loss from the tank (i.e., ${}_{b}IFR_{vm}$ case), this 76% reduction in seal losses translates to a 24% reduction in the total loss from the floating roof tank. Relative to fixed roof tank emissions, the additional control provided by the liquid-mounted primary and secondary seal system over the vapor-mounted primary seal system increases the effectiveness of the internal floating roof from 95.0 percent to 96.2 percent. (See Case 2 vs. Case 5 in Table 4-3.)

The currently available emissions test data suggest that the location of the seal (i.e., vapor- or liquid-mounted) and the presence of a secondary seal are the primary factors affecting seal losses. A liquid-mounted primary seal has a lower emissions rate and thus a higher control efficiency, than a vapor-mounted seal. A secondary seal, be it in conjunction with a liquid- or a vapor-mounted primary seal, provides an additional level of control. The emission test data (addressed in Appendix C) and the corresponding equations for estimating emissions (presented in Chapter 3) indicate that the type of seal employed (i.e., resilient tube seal, liquid-filled seal, etc.) plays a less significant role in determining the emissions rate. The type of seal is important only to the extent that the seal must be suitable for the particular application to which it is applied. For instance, a blade-type, elastomeric, wiper seal is commonly employed as a vapor-mounted primary seal or as a secondary seal for an internal floating roof. Because of its shape and materials of construction, this seal may not be suitable for use as a liquid-mounted primary seal. Resilient foam-filled tube and wedge shaped seals, on the other hand, can be used as both liquid- and vapor-mounted seals. Section 3.2.2 provides additional information on the types of seals that are suitable for various applications. The point to be made here, however, is that the seal type has a small impact on seal losses relative to the impact of the location of the seal and the presence of a secondary seal. Appendix C addresses the test data pertinent to this conclusion.

4.3.3 Deck Seam Losses

Depending on the type of floating roof employed, deck seam losses can contribute to the total loss from an internal floating roof. For the model tank used as a basis for comparison throughout this section (i.e., ${}_{b}IFR_{vm}$), deck seam losses are 10% of the total loss. When seal losses and fitting losses are controlled, the relative contribution to the total loss from deck seams increases. In the case of a bolted, noncontact, internal floating roof with liquid-mounted primary seals, controlled deck fitting losses, and secondary seals (${}_{b}IFR_{lm,cf,ss}$), deck seam losses contribute about 20 percent of the total loss.

Deck seam losses are inherent in several floating roof types. Any roof constructed of sheets or panels fastened by mechanical fasteners (bolted) is expected to experience deck seam losses. Two roof types were tested to determine deck seam losses (see Appendix C). The first was a bolted, aluminum, noncontact roof and the second was a bolted, aluminum panel-type, contact roof. The design of the mechanical fasteners employed on these two roof types varies significantly. In addition, one roof type floats above the liquid surface while the other floats in contact with the liquid surface. Despite these differences, the seams on these two roof types were found to emit at roughly the same rate per meter of seam. Deck seam losses, therefore, are considered to be a function of the length of the seams only and not the type of the seam or its position relative to the liquid surface.

The control for deck seam losses is achieved by selection of a roof type with vapor-tight deck seams. The welded deck seams on steel pan roofs are vapor tight. Also, it is likely that the fiberglass lapped seams of a glass fiber reinforced polyester roof (FRP) are vapor tight so long as the permeability of the liquid through the seam lapping materials is negligible. Some manufacturers provide gaskets for bolted metal deck seams. Deck seam gaskets also may retard deck seam losses by providing an additional barrier to diffusion and other possible deck seam loss mechanisms. The permeability of the liquid through the gasketing material also would be a factor. No test data are available to evaluate the effects of gaskets on deck seam losses.

Selection of a welded roof rather than a bolted roof will eliminate deck seam losses. The elimination of deck seam losses improves the overall effectiveness relative to a fixed roof tank of an internal floating roof with liquid-mounted primary seals, secondary seals and controlled fitting losses from a 96.6 to 97.3 percent control efficiency (see Case 6 vs. Case 7 in Table 4-3).

4.4 EXTERNAL FLOATING ROOF TANKS

External floating roof tanks emit less VOC per unit of storage capacity than fixed roof tanks. Depending on the rim seal system employed, they also can emit less VOC per unit of storage capacity than internal floating roof tanks. In the sense that external floating roof tanks may be used in place of fixed or floating roof tanks in new or replacement tank situations, they represent a control technology for the storage of VOL.

External floating roof tanks do not experience the fitting losses or deck seam losses that occur with most internal floating roof tanks. The external floating roof tanks are constructed almost exclusively of welded steel. This accounts for the absence of deck seam losses. Further, because of the roof design, few if any deck penetrations are necessary to accommodate fittings.

Penetrations in an external floating roof tank generally are needed only for some types of antirotation guides and emergency liquid drains. These fitting types are not employed on all external floating roofs. Because the number of deck penetrations in an external floating roof is small relative to the number in an internal floating roof, fitting losses from external floating roof tanks are assumed to be negligible. No emission test data, however, are available to verify this assumption.

Rim seal losses and withdrawal losses that are similar in nature to those experienced by internal floating roof tanks, do occur with external floating roof tanks. The only difference in this respect between external floating roofs and internal floating roofs is that the external floating roof seal losses are believed to be dominated by wind induced mechanisms.[1] Withdrawal losses in external floating roof tanks, as with internal floating roof tanks, are entirely a function of the turnover rate and inherent tank shell characteristics. No control measures have been identified that are applicable to withdrawal losses from floating roof tanks.

Rim seal losses from external floating roof tanks vary depending on the type of seal system employed. As with internal floating roof rim seal systems, the location of the seal (i.e., vapor- or liquid-mounted) is the most important factor affecting the effectiveness of resilient seals for external floating roof tanks. Liquid-mounted seals are more effective than vapor-mounted seals at reducing rim seal losses. Metallic shoe seals, which commonly are employed on only external floating roof tanks, are more effective than vapor-mounted resilient seals but less effective than liquid-mounted resilient seals.

The relative effectiveness of the various types of seals can be evaluated by analyzing the seal factors (K_s factor and wind velocity exponent, N) contained in Table 3-4 of the previous chapter. These seal factors were developed on the basis of emission tests conducted on a pilot scale tank. The results of the emission tests are published in an American Petroleum Institute bulletin.[3] To compare the relative effectiveness of the alternate seal systems, the seal factors were used with an assumed wind velocity (10 MPH) to generate directly comparable emission factors. These factors, which have meaning only in comparison to one another, are listed in Table 4-6 for alternative seal systems. In addition, the table contains control efficiencies (relative to the least effective seal system) and incremental control efficiencies (relative to the next higher emitting seal system) calculated directly from the emission factors. From the information in Table 4-6, it is clear that vapor-mounted primary seals on external floating roof tanks are significantly less effective than liquid-mounted or metallic shoe primary seals. Further, secondary seals provide an additional measure of control.

Considering the model tank that is used as a basis of comparison throughout this chapter, an external floating roof tank with liquid-mounted primary seals has about the same effectiveness as an internal floating roof tank with liquid-mounted primary seals and controlled fitting losses (see Case 10 vs. Case 5 in Table 4-3). An external floating roof

Table 4-6. EXTERNAL FLOATING ROOF TANK SEAL SYSTEM CONTROL EFFICIENCIES[a]

Seal system description	Emissions factor[a] $K_s(10)^N$	Seal loss control efficiency[b]	Incremental seal loss control efficiency[c]
Vapor-mounted resilient primary seal only	239	EFR assumed baseline seal technology	—
Vapor-mounted resilient primary seal and secondary seal	80	66%	66%
Metallic shoe primary seal only	38	84%	53%
Metallic shoe primary seal with a shoe-mounted wiper seal	13	95%	66%
Liquid-mounted resilient primary seal only	11	95%	Negligible difference
Metallic shoe primay seal with rim-mouted secondary seal	2.0	99%	82%
Liquid-mounted resilient primary seal with rim-mounted secondary seal	1.8	99%	Negligible difference

---

[a] For well designed sal systems with "average" gaps between the seal and the tank shell. Caculated from the K_s and N values listed in Table 3-4.

[b] The seal loss control efficiency relative to the least effective seal alternative.

[c] The seal loss control efficiency relative to the next less effective seal alternative.

tank with liquid-mounted primary and secondary seals yields the highest level of control achievable with the floating roof tank technology. A welded internal floating roof tank with liquid-mounted primary and secondary seals and controlled fitting losses reduces emissions over the fixed roof tank level by about 97.3 percent (see Case 7 in Table 4-3). An external floating roof tank with liquid-mounted primary and secondary seals exceeds this control level and achieves an estimated 99.0 percent reduction in emissions over the fixed roof tank level. The percentage reduction in emissions over the fixed roof tank case will vary, of course, with tank characteristics (e.g., tank size, vapor pressure of material stored). The external floating roof with liquid-mounted primary and secondary seals, however, remains the most effective floating roof tank technology from an emissions reduction standpoint. It must be recognized that this conclusion, as with all the conclusions in this chapter about the relative effectiveness of floating roof designs, is based on the results of emission tests conducted on a pilot scale tank (summarized in Appendix C). The test program was extensive in nature, but caution must be exercised when extrapolating results and conclusions to full size facilities that can be influenced by a large number of factors that cannot be easily controlled in a real environment (e.g., wind speed, temperature, etc.).

4.5 VAPOR CONTROL OR RECOVERY SYSTEMS ON FIXED ROOF TANKS

Losses from fixed roof tanks can be reduced by collecting the vapors and either recovering or oxidizing the VOC. In a typical vapor control system, vapors remain in the tank until the internal pressure reaches a preset level. A pressure switch, which senses the pressure buildup in the tank, then activates blowers to collect and transfer the vapors through a closed vent system. A redundant blower system is provided in this service to ensure that no vapors will be released to the atmosphere in the event of a primary blower malfunction. The closed vent system ducts the vapors to a recovery or oxidizer unit.

To prevent flashbacks from the control equipment, the vapors in the closed vent system from the tank may be saturated above the upper explosive limit in a saturator. Other safety precautions also are exercised such as nitrogen blanketing and use of flame arrestors. The particular precautions employed vary widely depending on the design of individual systems and the operating preference of individual companies.

4.5.1 Carbon Adsorption

Although there is little commercial operating experience for VOL applications of carbon adsorption, carbon adsorption for recovery of other organic vapors has been demonstrated, and the application of this technology to VOL recovery should not be difficult.[4] The general principle of adsorption is described below to facilitate the description of a carbon adsorption unit.

Carbon adsorption uses the principle of carbon's affinity for nonpolar hydrocarbons to remove VOC from the vapor phase. Activated carbon is the adsorbent; the VOC vapor that will be removed from the airstream is referred to as the adsorbate. The VOC vapor is adsorbed by a physical process at the surface of the adsorbent. The proposed VOC carbon adsorption unit consists of a minimum of two carbon beds plus a regeneration system. Two or more beds are necessary to ensure that one bed will be available for use while the other is being regenerated.

The carbon beds can be regenerated using either steam or vacuum (Figure 4-3). In steam regeneration, steam is circulated through the bed, raising the VOC vapor pressure. The vaporized VOC is thus removed with the steam. The steam-VOC mixture is condensed, usually by an indirect cooling water stream, and routed to a separator. The VOL is then decanted and returned to storage, and the contaminated water is sent to the plant wastewater system for treatment. Cooling water, electricity, and steam are the required utilities for a steam regeneration system. The other method of regenerating the carbon, vacuum regeneration, is performed by pulling a high vacuum on the carbon bed. The VOC vapor desorbed by this process is condensed and returned to storage.

4.5.2 Oxidation Units

Thermal and catalytic oxidizers have been used successfully to dispose of VOC vapors in other industries. Thermal oxidation is the most direct means of VOC vapor disposal, uses the fewest moving parts and is the simplest to operate. The vapor mixture is injected via a

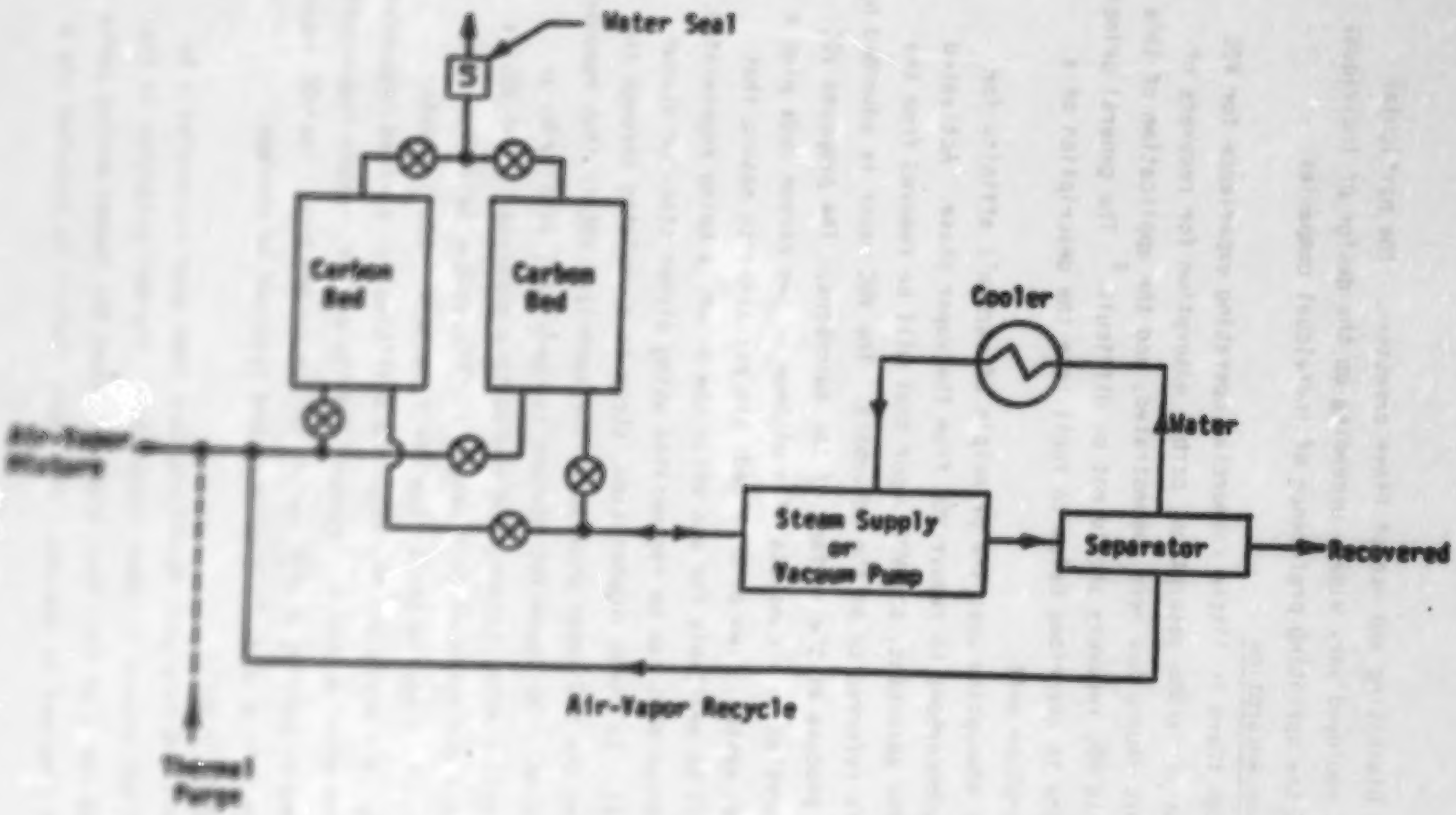

Water Seal
S
Carbon Bed
Carbon Bed
Cooler
Water
Air-Vapor Mixture
Steam Supply or Vacuum Pump
Separator
Recovered
Air-Vapor Recycle
Thermal Purge

Figure 4-3. Carbon adsorption unit using steam regeneration.

burner manifold into the combustion area of the incinerator. Pilot burners provide the ignition source, and supplementally fueled burners add heat when required. The amount of combustion air needed is regulated by temperature-controlled dampers. Figure 4-4 shows a typical thermal oxidation unit.

Flashback prevention and burner stability can be achieved by saturating the vapors with a suitable hydrocarbon to a concentration above the upper explosive limit. In addition, two water seal flame arrestors can be used to ensure that flashbacks do not propagate from the burner to the rest of the closed vent system. As mentioned, safety practices and equipment vary widely depending on system design and the operating preference of individual companies. A significant advantage of thermal oxidizers is that they can dispose of a wide range of VOLs. Fuel consumption and catalyst repacement are the major cost factors in considering thermal and catalytic oxidation.

4.5.3 Refrigerated Vent Condensers

A refrigerated vent condenser collects the VOL vapors exiting through the vents and condenses them. The vents open and close as the pressure within the tank increases and decreases. Pressure changes occur when the tank is being filled or emptied, or when the temperature changes. Condensers are designed to handle the maximum flow rate expected at any given time, which usually occurs during filling. Freezing of moisture or VOL is handled by a defrost-separation-recovery system. The efficiency of vent condensers depends upon the vapor concentration and the condensing temperature.

4.5.4 Control Efficiencies of Vapor Recovery or Control Systems

The carbon adsorption vapor control system is estimated to reduce emissions from the VOL storage vessel by approximately 98 percent. This efficiency is based on a measured carbon adsorption unit efficiency of 98 percent during gasoline loading operations.[5]

The thermal oxidation vapor control system is estimated to reduce emissions from the VOC storage vessel by approximately 98 percent. This efficiency is based on a measured thermal oxidation unit efficiency of 98 percent during a wide variety of operations.[6,7] At very low flow rates, or at low VOC inlet concentrations, somewhat less than 98 percent of the VOC vapors leaving the storage vessel may be incinerated.

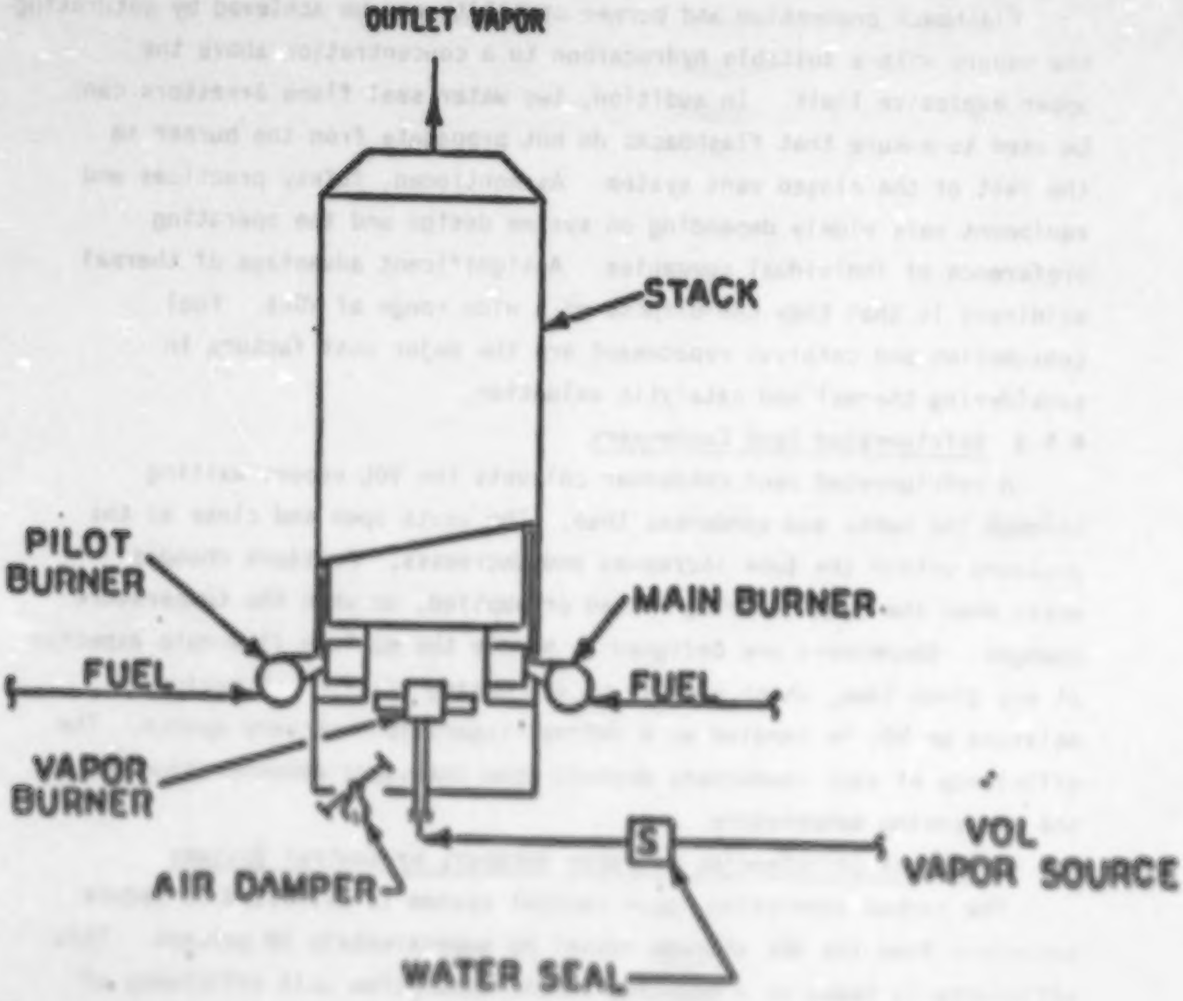

OUTLET VAPOR
STACK
PILOT BURNER
MAIN BURNER
FUEL
FUEL
VAPOR BURNER
S
VOL VAPOR SOURCE
AIR DAMPER
WATER SEAL

Figure 4-4. Thermal oxidation unit.[8]

4.6 REFERENCES

1. The American Petroleum Institute (API), Draft Document, Evaporation Loss from Internal Floating Roof Tanks, API Publication 2519, Third Edition, 1982.

2. McAllister, Dr. R. Memorandum to the Volatile Organic Liquid Storage Standard Docket (No. A-80-51) regarding permeability losses through seal materials and deck seal loss mechanisms. Dated February 1983.

3. Evaporation Loss from External Floating Roof Tanks. Bulletin No. 2517. American Petroleum Institute. Washington, D.C. 1980.

4. U.S. Environmental Protection Agency, Evaluation of Control Technology from Benzene Transfer Operations, Research Triangle Park, North Carolina, EPA-450/3-78-018, April 1978.

5. Letter from McLaughlin, Nancy D., U.S. Environmental Protection Agency to D. Ailor, TRW Inc. Comments on the benzene storage model plants package. May 3, 1979.

6. Letter and attachments from D. C. Mascone, EPA/CPB, to J. R. Farmer, EPA. June 11, 1980. Memo concerning thermal incinerator performance for NSPS.

7. U.S. Environmental Protection Agency. Organic Chemical Manufacturing, Volume 4: Combustion Control Devices. Research Triangle Park, North Carolina. Publication No. EPA-450/3-80-026. December 1980.

5. MODIFICATIONS AND RECONSTRUCTION

After the new source performance standards (NSPS) have been promulgated in accordance with Section 111 of the Clean Air Act, as amended, all affected facilities will include those facilities constructed, modified, or reconstructed after the date of promulgation. The NSPS could also apply to an existing facility as defined in 40 CFR 60.2. An existing facility would become an affected facility if it were determined to be modified or reconstructed. This chapter describes the conditions under which an existing facility would become subject to the standards of performance. The enforcement division of the appropriate EPA regional office would make the final determination as to whether a source were modified or reconstructed and would therefore become an affected facility. This chapter also defines potential modifications and reconstructions.

5.1 PROVISIONS FOR MODIFICATIONS AND RECONSTRUCTION

5.1.1 Definition of Modification

It is important that these provisions be understood before considering examples of potential modifications. Section 60.14 defines modification as follows:

> "Except as provided under paragraphs (e) and (f) of this section, any physical or operational change to an existing facility which results in an increase in the emission rate to the atmosphere of any pollutant to which a standard applies shall be considered a modification within the meaning of Section 111 of the Act. Upon modification, an existing facility shall become an affected facility for each pollutant to which a standard applies and for which there is an increase in the emission rate to the atmosphere."

Paragraph (e) lists certain physical or operational changes that are not considered modifications, regardless of any changes in the emission rates. These changes are:

1. Routine maintenance, repair, and replacement.
2. An increase in the production rate not requiring a capital expenditure as defined in Section 60.2.
3. An increase in the hours of operation.
4. Use of an alternative fuel or raw material if, prior to the standard, the existing facility was designed to accommodate that alternate fuel or raw material, except for conversion to coal required for energy consideration.
5. The addition or use of any system or device whose primary function is the reduction of air pollutants, except when an emission control system is removed or replaced by a system considered to be less efficient.
6. The relocation or change in ownership of an existing facility.

Paragraph (b) specifies that an increase in emissions is defined in kilograms per hour and delineates the methods for determining the increase, including the use of emission factors, material balances, continuous monitoring systems, and manual emission tests. Paragraph (c) affirms that the addition of an affected facility to a stationary source does not make any other facility within that source subject to standards of performance. Paragraph (f) simply provides for superseding any conflicting provisions.

5.1.2 Definition of Reconstruction

Section 60.15 regarding reconstruction states:

> "If an owner or operator of an existing facility proposes to replace components, and the fixed capital cost of the new components exceeds 50 percent of the fixed capital cost that would be required to construct a comparable entirely new facility, he shall notify the Administrator of the proposed replacements. The notice must be postmarked 60 days (or as soon as practicable) before construction of the replacements is commenced. . ."

The reconstruction provision of the regulation prevents an owner or operator from continuously replacing an operating process, except for support structures, frames, housing, etc. in an attempt to avoid compliance with NSPS.

5.2 APPLICABILITY TO VOLATILE ORGANIC LIQUID STORAGE

This section outlines the applicability of the modification provisions to existing plants and describes the applicability of reconstruction to this industry. This is only a general discussion of changes that would require an existing facility to comply with the standard. The final determination would be made by the appropriate EPA regional office on a case-by-case basis.

5.2.1 Modification Examples

Few, if any, modifications can be made to a storage vessel. Because replacement of frame, housings, and supporting structures would not increase emissions from a storage vessel, such a replacement would not constitute a modification. For the purposes of applicability of these CAA provisions to a storage vessel, a change in the stored liquid from a reactive VOC non-emitting liquid to a reactive VOC emitting liquid does not constitute an operational change; the vessel operation would be identical for all liquids. A change of liquids, therefore, does not constitute a modification.

5.2.2 Reconstruction Examples

The reconstruction provision of the regulation is relatively straightforward in that, regardless of the VOC emission rate, an existing facility may become an affected facility if the fixed capital cost of new components exceeds 50 percent of the fixed capital cost of a comparable, entirely new facility. It is expected that only under catastrophic circumstances (e.g., total destruction of the storage vessel by fire or explosion, collapse of an external floating roof or collapse of a fixed roof) would a facility be affected by the NSPS reconstruction provision. Because associated structures (frames, housing, etc.) are not part of a tank, replacement of such a structure would not constitute a reconstruction.

6. REGULATORY ALTERNATIVES AND MODEL PLANTS

This chapter defines control options that are to be evaluated as regulatory alternatives in developing standards of performance for the storage of volatile organic liquids (VOL). The technologies that constitute the control options are applicable to specific storage vessel types. A regulatory alternative refers to a potential requirement that a particular control technology or an array of technologies (a control option) be applied to all new, modified, and reconstructed storage vessels. In evaluating the economic impacts of the regulatory alternatives, model plants are employed. Both the regulatory alternatives and the model plants are presented in this chapter.

6.1 REGULATORY ALTERNATIVES

The methodology for selecting the Best Demonstrated Technology (BDT) for VOL storage vessels focuses on the impacts and costs of applying control options to specific tank types. Discussions of this methodology and the selection of BDT are contained in the preamble. The nationwide environmental and economic impacts of BDT, however, must be evaluated. Therefore, in order to structure and to perform these analyses, potential control options that might comprise BDT have been arrayed into regulatory alternatives.

Three criteria were used to select control options for evaluation as regulatory alternatives. They are:

1. Potential emission reduction;
2. Cost; and
3. Applicability.

In Chapter 4 the potential control technologies that may reasonably constitute BDT are identified. Table 6-1 presents the potential emission reduction obtained by various equipment types on various emission sources.

and Table 4-3 presents the emission reduction obtained over a fixed roof tank baseline. In Chapter 8, Tables 8-20 through 8-24 present the individual tank cost effectiveness analysis of potential control technologies for BDT.

To analyze the impacts of regulatory alternatives, the emissions from the baseline (no additional Federal regulation) must be calculated. Therefore, Regulatory Alternative 0 would require no additional equipment over currently required controls and represents the VOL baseline. All emissions and costs of subsequent regulatory alternatives are analyzed relative to the baseline data.

Current regulations (the baseline) allow fixed roof storage vessels to be constructed in certain size and vapor pressure ranges. Because BDT could involve internal floating roof tanks, it was decided to examine the impacts of requiring that fixed roof tanks be constructed as internal floating roof tanks. As the tables in Chapter 4 demonstrate, building new internal floating roof tanks with vapor-mounted primary seals and typical fittings in place of fixed roof tanks, provides a 93 percent emission reduction in the model storage vessel. (The model vessel is described in Chapter 4.) This is equivalent to the level of control required by the NSPS for petroleum liquid storage vessels. This equipment (internal floating roof, vapor-mounted primary seal, and uncontrolled fittings) was selected as Regulatory Alternative I.

Internal floating roof tanks have four emission sources. These are:

1. Rim seal losses;
2. Fitting losses;
3. Deck seam losses; and
4. Working losses.

Equipment that will reduce emissions from these sources is available. Therefore, potential emission reductions from these sources were examined for the development of regulatory alternatives.

As demonstrated in Chapter 4, equipping internal floating roof tanks with liquid-mounted primary seals instead of vapor-mounted primary seals would provide an additional emissions reduction by decreasing the rim seal losses. To examine the impacts of this equipment, Regulatory

Alternative II would require each tank to be equipped with an internal floating roof with a liquid-mounted primary seal but would allow uncontrolled fittings. This alternative would reduce fixed roof tank emissions by 95 percent.

The next more stringent control option would require an emission reduction from the fittings on internal floating roof tanks. To examine the impacts of this equipment, Regulatory Alternative III is formulated by requiring that the internal floating roof be equipped with a liquid mounted primary seal and controlled fittings. This alternative would reduce fixed roof tank emissions by about 96 percent.

At this point in the development of regulatory alternatives all the emission sources of the internal floating roof with the exception of working losses and deck seams have been controlled. There are no equipment controls for working losses, so no regulatory alternative to examine the impacts of controlling these losses could be developed. In examining controls for deck seams, the information presented in Tables 8-21 and 8-22 demonstrates that it is more cost effective to require a further emission reduction from the rim seal area than from deck seams. To examine this, Regulatory Alternative IV was formulated by requiring that an internal floating roof be equipped with a liquid-mounted primary seal and a secondary seal and with controlled fittings. This group of control technologies reduces the fixed roof tank emissions by about 97 percent.

Regulatory Alternative V requires that deck seam emissions be reduced through the use of welded decks in addition to the equipment required by Alternative IV. This array of equipment reduces fixed roof tank emissions by about 97 percent.

At this point in the development of regulatory alternatives all of the emissions sources from internal floating roof tanks have been reduced to the greatest possible extent. Therefore, other control options that do not involve internal floating roofs were examined.

Tanks could be equipped with vapor control recovery systems. Such a system would be expected to provide about 95 percent emission reduction. This system is not as efficient as the control equipment required by Regulatory Alternatives IV and V and is much more costly. Therefore, vapor control or recovery systems were rejected as a regulatory alternative.

External floating roof tanks with liquid-mounted or mechanical shoes primary seals and a secondary seal were examined as a possible regulatory alternative. External floating roof tanks are only available in size ranges that are generally larger than the size range of most VOL tanks; 59 percent of VOL storage vessels are projected to have diameters less than 6 meters. For these reasons external floating roof tanks were not selected for evaluation as a regulatory alternative.

In summary, the regulatory alternatives would require that each vessel storing a VOL be equipped with the control technology described as follows:

- Regulatory Alternative 0 – no additional control over baseline.
- Regulatory Alternative I – an internal floating roof with a vapor-mounted primary seal (IFR_{vm}).
- Regulatory Alternative II – an internal floating roof with a liqud-mounted primary seal (IFR_{lm}).
- Regulatory Alternative III – an internal floating roof with a liquid-mounted primary seal and controlled deck fittings ($IFR_{lm,cf}$).
- Regulatory Alternative IV – an internal floating roof with a liquid-mounted primary seal controlled deck fittings, and a continuous secondary seal ($IFR_{lm,cf,ss}$).
- Regulatory Alternative V – a welded internal floating roof with a liquid-mounted primary seal, controled deck fittings and a continuous secondary seal ($_{w}IFR_{lm,cf,ss}$).

6.2 MODEL PLANTS

Model plants are developed for use in evaluating the worst-case economic impacts that the regulatory alternatives may have on affected industries. For VOL storage, as is discussed in Chapter 7, nationwide impacts are projected from an extrapolation of the 1977 tank volume and vapor pressure distribution as presented in Section 3.1. The model plants described in this chapter are used to evaluate potential adverse economic impacts on individual plants. (The economic impact analyses are presented in Chapter 9.) Because there is a greater potential adverse economic impact upon small facilities, small plants or facilities are selected as worse-case examples. The model plants consist of a model terminal and a model producer/consumer. These model plants are based on actual facilities that have parameters suitable for use in the economic impact analysis.

6.2.1 Model Terminal

The model terminal data are presented in Table 6-1. These data are formatted to facilitate comparison with the nationwide VOL storage terminal statistics presented in Chapter 3 (see Table 3-3). The model has roughly as many vessels as the average terminal. However, for the most part, the vessels in the model terminal are smaller in size than the vessels in the average terminal. In general, small vessels are more expensive per unit volume of storage capacity to control than larger vessels. Also, the volume of material that passes through the model terminal is small. Because of this, the additional costs that result from the implementation of regulatory alternatives are higher on a per-volume-throughput basis. Finally, as a general rule, any small business faces higher costs of capital than a large corporation. It is assumed that the model terminal operates as an independent facility and would, therefore, face these higher costs of capital.

6.2.2 Model Producer/Consumer

The model producer/consumer represents a small chemical manufacturing facility. It is assumed that a small facility is likely to be more severely affected by the regulatory alternatives under consideration. The model producer/consumer facility consists of small vessels and produces small amounts of an inexpensive product. The lower product price minimizes potential recovery credits associated with the installation of controls.

The model producer/consumer data are presented in Table 6-2. The model facility produces fewer than 4.54×10^6 kilograms per year (10^7 pounds per year) of a product that sells for \$0.35 per kilogram (\$0.16 per pound). Both the production capacity and product price for the model producer/consumer are smaller than the average capacity and price for organic chemicals estimated from the Organic Chemical Producters Data Base (see Chapter 9).

Table 6-1. MODEL TERMINAL

Terminal capacity - 14,000 m^3 (≅3.6 x 10^6 gal)

Number of tanks - 48

Volume of smallest tank - 3.8 m^3 (≅1,000 gal)

Average tank volume - 300 m^3 (≅80 x 10^3 gal)

Volume of largest tank - 2,300 m^3 (≅600 x 10^3 gal)

Average number of annual turnovers per tank - 2.9

Terminal throughput - 39,000 m^3 (≅10,000 x 10^3 gal)

Table 6-2. MODEL PRODUCER/CONSUMER

Plant production capacity - <4.5 x 10^6 kg/year (<10^7 lb/yr)

Plant tank capacity - 2,000 m^3 (≅530 x 10^3 gal)

Number of tanks - 11

Average tank volume - 190 m^3 (≅50 x 10^3 gal)

Volume of largest tank - 330 m^3 (≅88 x 10^3 gal)

Volume of smallest tank - 14 m^3 (≅4,000 gal)

7. ENVIRONMENTAL IMPACTS

7.1 INTRODUCTION

This chapter discusses the fifth-year environmental impacts of each regulatory alternative presented in Chapter 6. The fifth-year impacts are the impacts that would be incurred by the new, modified, and reconstructed facilities constructed during the five years following implementation of the regulatory alternatives. In these analyses, a base year of 1983 is assumed (i.e., the regulatory alternatives would be in force starting in 1983). The nationwide impacts that are evaluated include:

- air pollution impacts;
- water pollution impacts;
- energy impacts; and
- other environmental concerns.

The nationwide impacts are developed from the number of affected facilities (i.e., VOL storage vessels) projected to be constructed during the five years following the baseline date. Chapter 9 explains the derivation of a bivariate distribution, by tank size and vapor pressure of the VOL stored, of the numbers of affected facilities that are projected to be constructed between 1983 and 1988. The potential environmental impacts of the regulatory alternatives are estimated with this bivariate distribution of affected facilities and the knowledge of the baseline control levels (discussed in Section 3.3) that would result in the absence of performance standards.

7.2 AIR POLLUTION IMPACTS

Adoption of any of the regulatory alternatives will reduce VOC emissions in the years following the implementation. The magnitude of the emissions reductions to be achieved by the regulatory alternatives is estimated based on the estimated five-year total number of affected new and replacement tanks to be constructed, the tank size vapor pressure percentage distribution discussed in Chapter 9, and the equations for predicting emissions from the various VOL storage vessel equipment types (presented in Section 3.2). An average emission rate for tanks in each tank size/vapor pressure interval in the distribution is calculated by using the average capacity of the interval, the average vapor pressure of the interval, and the average number of tank turnovers for the tank size range. The emissions per tank in the interval are then multiplied by the number of tanks in the tank size/vapor pressure interval. The total emissions rate for a given regulatory alternative is determined by summing across the tank size/vapor pressure intervals. This procedure is repeated for the baseline control level and each regulatory alternative. Emissions reductions are determined by subtracting the baseline emissions rate from the emissions rate for each regulatory alternative.

Table 7-1 and 7-2 list the emission rates and emission reductions, respectively, associated with each regulatory alternative. The emission values in the tables are in megagrams per year, reflecting the annual emissions or emission reduction from the affected facilities that are projected to be constructed during the five years following the baseline date (1983-1988). Each table provides estimates for ten alternate tank size/vapor pressure cutoff levels. For example, row two of Table 7-1 provides emission estimates assuming that the minimum tank size affected by the regulation is 75 m^3 (20,000 gallons) and the minimum vapor pressure affected by the regulation is 3.5 kPa (0.5 psia). A projected 3,749 tanks will be constructed in the five years following 1983 that are above these cutoff conditions and, therefore, would be affected by an NSPS that implemented cutoffs at these levels. The tanks regulated at this cutoff will emit 10,845 Mg/yr under the baseline control level, 2,502 Mg/yr under Regulatory Alternative I and so forth for the remaining regulatory alternatives. Referring to Table 7-2 for this same cutoff, Regulatory Alternative I will effect a 8,343 Mg/yr reduction in VOC emissions; Regulatory Alternative II will effect a 8,780 Mg/yr reduction in VOC emissions, and so forth for the remaining regulatory alternatives.

Table 7-1. FIFTH-YEAR EMISSIONS RESULTING FROM THE REGULATORY ALTERNATIVES

Cutoff Level Tank Size/Vapor Pressure		Number of Affected Facilities[a]	Emissions for Each Regulatory Alternative (Mg/yr)					
m^3/kPa	1000 gal/psia		Baseline[b]	I[c]	II[d]	III[e]	IV[f]	V[g]
0/0	0/0	16,086	22,171	4,272	3,659	2,540	2,308	2,047
75/3.5	20/0.5	3,748	10,845	2,502	2,065	1,498	1,333	1,110
75/6.9	20/1.0	2,686	7,009	2,273	1,871	1,357	1,205	997
75/10.3	20/1.5	2,027	2.960	2,032	1,670	1,211	1,074	885
114/3.5	30/0.5	3,167	9,685	2,245	1,841	1,354	1,201	985
114/6.9	30/1.0	2,287	5,993	2,046	1,673	1,230	1,089	887
114/10.3	30/1.5	1,726	2,072	1,832	1,495	1,099	972	789
151/3.5	40/0.5	2,945	9,240	2,148	1,757	1,300	1,152	939
151/6.9	40/1.0	2,138	5,610	1,961	1,601	1,183	1,047	848
151/10.3	40/1.5	1,628	1,762	1,762	1,436	1,060	937	757

[a] The number of new, modified, and reconstructed storage vessels that meet the respective cutoff criteria and, therefore, would be affected by the regulatory alternatives.

[b] $b^{IFR}{}_{vm}$ and fixed roof tank mixed baseline (see Section 3.3).

[c] $b^{IFR}{}_{vm}$

[d] $b^{IFR}{}_{lm}$

[e] $b^{IFR}{}_{lm,cf}$

[f] $b^{IFR}{}_{lm,cf,ss}$

[g] $w^{IFR}{}_{lm,cf,ss}$

Table 7-2. FIFTH-YEAR EMISSIONS REDUCTIONS RESULTING FROM THE REGULATORY ALTERNATIVES

Cutoff Level Tank Size/Vapor Pressure		Number of Affected Facilities[a]	Emissions Reduction Obtained by Each Regulatory Alternative (Mg/yr)					
m^3/kPa	1000 gal/psia		Baseline[b]	I[c]	II[d]	III[e]	IV[f]	V[g]
0/0	0/0	16,086	0	17,899	18,512	19,631	19,863	20,124
75/3.5	20/0.5	3,748	0	8,343	8,780	9,347	9,512	9,735
75/6.9	20/1.0	2,686	0	4,736	5,138	5,652	5,804	6,012
75/10.3	20/1.5	2,027	0	928	1,290	1,749	1,886	2,075
114/3.5	30/0.5	3,167	0	7,440	7,844	8,331	8,484	8,700
114/6.9	30/1.0	2,287	0	3,947	4,320	4,763	4,904	5,106
114/10.3	30/1.5	1,726	0	240	577	973	1,100	1,283
151/3.5	40/0.5	2,945	0	7,092	7,483	7,940	8,088	8,301
151/6.9	40/1.0	2,138	0	3,649	4,009	4,427	4,563	4,762
151/10.3	40/1.5	1,628	0	0	326	702	825	1,005

[a] The number of new, modified, and reconstructed storage vessels that meet the respective cutoff criteria and, therefore, would be affected by the regulatory alternatives.

[b] $b^{IFR}{}_{vm}$ and fixed roof tank mixed baseline (see Section 3.3).

[c] $b^{IFR}{}_{vm}$

[d] $b^{IFR}{}_{lm}$

[e] $b^{IFR}{}_{lm,cf}$

[f] $b^{IFR}{}_{lm,cf,ss}$

[g] $w^{IFR}{}_{lm,cf,ss}$

7.3 WATER QUALITY AND SOLID WASTE IMPACTS

The control technologies selected as regulatory alternatives do not generate wastewater or solid waste during their operation as control devices. During tank turnarounds and periods when tanks are not in service, however, wastewater and solid waste may be generated. Inspection and maintenance operations can generate both wastewater and liquid/solid wastes that require treatment or special disposal techniques. Most major inspections and/or repairs require that the vessel be cleaned and degassed. The concern is that the environment inside the tank be free of potential explosive and toxic hazards prior to introducing personnel for inspections or repairs.

Cleaning and degassing generally involves the following steps[1]:

1. Removing residual product with a vacuum truck;
2. Lossening rust scale, if present, with high pressure water and removing debris;
3. Washing the tank with high pressure water and detergents; and
4. Rinsing the tank with water.

The residual product constitutes a waste that, depending on the nature of the VOL stored in the tank, may have to be disposed of with conventional solid waste disposal techniques or as a hazardous waste in compliance with the requirements of the Resource Conservation and Recovery Act (RCRA). The washwater, again depending on the nature of the VOL stored, constitutes wastewater for treatment in conventional wastewater treatment systems, or sometimes hazardous waste for disposal in compliance with RCRA. Another degassing methodology involves the application of a sustained forced draft to the interior of the vessel for a sufficient period to evaporate all residual product. This technique generally involves no wastewater or hazardous solid waste disposal. However, air emissions do result.

For the most part, tank degassing and the resultant waste impacts occur irrespective of the regulatory alternatives. On the average, tanks are cleaned, degassed and inspected on about a 10-year cycle.

7.4 ENERGY IMPACT

The control technologies selected for the regulatory alternatives do not increase the power or other energy requirements of the VOL storage vessels. Therefore, no energy impacts are attributable to the regulatory alternatives.

7.5 OTHER ENVIRONMENTAL CONCERNS

7.5.1 Irreversible and Irretrievable Commitment of Resources

The regulatory alternatives would not preclude the development of future control options nor would they curtail any beneficial use of the environment. No long-term environmental losses would result from the regulatory alternatives.

7.5.2 Environmental Impact of Delayed Standards

The only environmental impact associated with a delay in proposing and promulgating the standard would be an increase in VOC emissions from storage tanks attributable to the construction of new tanks.

7.6 REFERENCES

1. Memorandum from J. L. Shumaker to W. Moody of TRW Environmental Division regarding Retrofit IRF and Degassing Costs, December 21, 1982.

8. COST ANALYSIS

This chapter summarizes the cost analysis data. Installed capital costs are presented in Section 8.1 for the types of equipment specified in the regulatory alternatives outlined in Chapter 6. For each type of equipment, cost estimates are presented for the range of tank sizes commonly employed in the storage of volatile organic liquids (VOL). Cost data also are presented for several control alternatives (external floating roof tanks and vapor control equipment) that are considered in Chapter 6 but that are not selected as regulatory alternatives. In addition to the cost estimates for individual tank size/control alternative combinations, the aggregate cost impacts from applying the regulatory alternatives to the model plants are estimated. Sections 8.1 through 8.4 present estimates of the capital costs, annualized costs, and cost effectiveness for model terminal and model producer/consumer facilities. Model plants are discussed in detail in Chapter 6.

All costs are calculated as average costs over the cost of the baseline control level presented in Section 3.3. For the purposes of the cost analysis presented in this chapter, all tanks with a capacity greater than or equal to 75 cubic meters (20,000 gallons) and storing a liquid with a true vapor pressure greater than or equal to 3.5 kilopascals (0.5 psia) are assumed to be affected by the regulatory alternatives. Because the model terminal and model producer/consumer facilities will not be used to evaluate the effectiveness of the regulatory alternatives in controlling emissions, no emission information is presented in this chapter.

The cost analysis follows a prescribed approach. Capital costs, which represent the initial investment for control equipment and installation, are estimated based on vendor quotes and EPA documents. From these estimates, correlations and factors have been developed to approximate capital costs for the range of tank sizes commonly used in the industry. The capital cost is annualized by applying a capital recovery charge, which is based on an estimated equipment lifetime and the interest rate on the capital, and by adding costs for taxes and insurance. The total annualized cost, excluding product recovery credits, attributable to each regulatory alternative is estimated by adding operating costs to the annualized capital cost. The total annualized cost, including product recovery credits, is estimated by subtracting the value of the recovered product from the annualized costs. Cost effectiveness is the total annualized cost divided by the emission reductions obtained by applying each regulatory alternative.

8.1 CAPITAL COSTS

The capital costs for the regulatory alternatives are based on cost estimates obtained from industry vendors and EPA reports.[1,2,3] Vendors were contacted and asked to provide estimates of the costs to construct fixed roof tanks, external floating roof tanks, and secondary seals, as well as the cost to install internal floating roofs in fixed roof tanks. (See Tables 8-1, 8-2, 8-3, and 8-4.) Internal floating roof cost data are based on a fourth-quarter 1982 survey of equipment manufacturer's prices. Other cost estimates are based on data collected in a similar manner in late 1979 and early 1980. These estimates have been scaled based on Chemical Engineering general cost indexes[4] to reflect second-quarter 1982 dollar estimates. All capital costs are at least equivalent to study estimates (±30 percent accuracy).

The capital cost of an internal floating roof depends mainly upon the liquid surface area. Therefore, the capital costs for these devices are given only as a function of the tank diameter, which is directly related to surface area. The cost of a fixed roof tank, however, is a function of the volume capacity of the tank*. Tank and roof costs

---

* An estimating technique has been developed to relate tank volume to tank height and diameter and thereby aid the comparison of fixed roof tank costs to floating roof costs. The formula is based on the fact that tank heights generally increase in about 2.62 meter (8 foot) increments (due to the width of sheet steel) and that for other than small tanks, the height to diameter ratio rarely exceeds unity in industry practice. The formula, which has been used in the development of the capital cost tables, is as follows:

Tank capacity (V) in cubic meters	Tank height (H) in meters	Tank diameter (D) in meters
0-45	2.62	
46-91	5.25	$D = \left(\frac{4V}{\pi H}\right)^{1/2}$
92-307	7.87	
308-1,136	10.5	
1,137-11,590	13.1	
>11,590	15.7	

Table 8-1. ESTIMATED INSTALLED CAPITAL COST OF A FIXED ROOF TANK[5,6] (second-quarter 1982 dollars)

Tank volume, (m^3)	Tank diameter, (m)	Tank cost[a,b] ($)
75	4.3	13,300
150	4.9	19,900
250	6.4	26,700
500	7.8	39,800
1,000	11.0	59,400
5,000	22.0	150,400
10,000	31.2	224,300

[a] Estimated from the equation: Cost (\$1000) = $0.883\ V^{0.577}$; where, V = tank volume in cubic meters; with correlation coefficient $r^2 > 0.99$. This equation yields first-quarter 1980 cost estimates that were scaled by a factor of 1.25 to reflect second-quarter 1982 prices.[4]

[b] Excluding the cost of the foundation, land, etc. that are not affected by the regulatory alternatives.

Table 8-2. ESTIMATED INSTALLED CAPITAL COST OF A NONCONTACT INTERNAL FLOATING ROOF[3]
(fourth-quarter 1982 dollars)

Tank diameter, (m)	Basic roof cost[a] ($)	Cost with liquid-mounted primary seal[b] ($)	Cost with liquid-mounted primary seal and controlled deck fittings[c] ($)	Cost with liquid-mounted primary seal, controlled deck fittings and secondary seal[d] ($)
5	6,280	6,320	6,320	7,620
10	11,600	11,680	11,680	14,300
15	17,000	17,120	17,120	21,000
20	22,300	22,460	22,460	27,600
25	27,700	27,900	27,900	34,400
30	33,000	33,250	33,250	41,000

[a] Estimated from the equation: Cost ($) = 1,069 D + 939; where, D = tank diameter in meters; with the correlation coefficient $r^2 = 0.889$. This correlation generates installed cost estimates for an aluminum noncontact internal floating roof with a vapor mounted wiper type seal.

[b] The additional cost of the liquid-mounted primary seal over an elastomeric wiper seal is estimated to be $2.60 per linear meter of circumference based on quotes from one vendor.[3]

[c] Controlled deck fittings include a gasketed, bolted cover, access hatch; a gasketed, bolted cover automatic gauge float well; pipe columns with a flexible fabric sleeve seals; a gasketed sliding cover for the ladder well; a sample well with a split fabric seal and 10% open area; and a weighted, mechanical actuation, gasketed, vacuum breaker. Based on vendor estimates, the additional cost of controlled fittings over the cost of the normally installed deck fittings is negligible.

[d] Cost of secondary seal is estimated to be $85 per linear meter of tank circumference. This is the average price of 13 seals from 8 different vendors.[3]

Table 8-3. ESTIMATED INSTALLED COST OF A WELDED CONTACT INTERNAL FLOATING ROOF WITH SECONDARY SEALS[3]
(fourth-quarter 1982 dollars)

Tank diameter (m)	Roof cost[a] ($)
5	15,900
10	30,000
15	44,000
20	58,100
25	72,100
30	86,100

---

[a] The basic cost of the roof and primary seal is estimated from the equation: cost ($1000) = 1.91 + 2.54D; where D equals the tank diameter in meters with the correlation coefficient $r^2 = 0.883$. The additional cost of a secondary seal is estimated based on the factor, $85 per linear meter of circumference. The secondary seal cost is the average price of 13 seals from 8 different vendors.

Table 8-4. ESTIMATED INSTALLED CAPITAL COST OF EXTERNAL FLOATING ROOF TANKS WITH SECONDARY SEALS[5,6,7] (second-quarter 1982 dollars)

Tank volume, (m^3)	Tank diameter, (m)	Tank cost[a,b] ($)
75	4.3	22,100
150	4.9	32,300
250	6.4	42,300
500	7.8	61,900
1,000	11.0	89,900
5,000	22.0	218,000
10,000	31.2	319,000

[a] Cost of tank estimated from the equation: Cost (\$1000) = $1.54\ V^{0.552}$; where, V = tank volume in cubic meters; with the correlation coefficient $r^2 = 0.98$. This equation yields first-quarter 1980 cost estimates that[4] were scaled by a 1.25 factor to reflect second-quarter 1982 dollars.

[b] The additional cost of the secondary seal is estimated to be \$85 per linear meter of roof circumference.[5]

are not related to the vapor pressure of the material stored in the range of products potentially affected by a VOL storage regulation (i.e. <~11 psia). For each type of equipment (i.e., internal floating roof, fixed roof tank, etc.) an equation of predicted capital costs was derived from the available data (vendor quotes). These equations are used in all subsequent cost analyses.

Table 8-1 presents costs for fixed roof tanks. These are installed capital costs including the cost of materials, transportation, labor, testing, and other vendor-incurred costs associated with erection of the tank. The estimates assume that a suitable location and foundation are available. Examples of the costs that are excluded include the cost of land, providing utilities to the site, and a concrete foundation. Such costs are fixed and constant irrespective of possible regulations for VOL storage vessels. Since they do not affect the regulatory decisions, they are not considered in the cost analysis.

Table 8-2 presents installed cost estimates for internal floating roofs with successively more stringent (i.e. lower emitting) alternative equipment. As discussed in Chapter 4, noncontact roofs are constructed of primarily aluminum materials. The basic roof costed in the table is equipped with a single, vapor-mounted, wiper type, deck perimeter seal (primary seal). The next costed alternative is a liquid-mounted, resilient tube, primary seal in place of the vapor-mounted wiper type seal. The third alternative includes the liquid-mounted primary seal, but adds "controls" to certain deck fittings. Deck fittings and the "controls" for deck fittings are described in Chapter 3 and Chapter 4, respectively. Briefly, "controls" for deck fittings are gaskets for covers, sleeve seals for support columns and the use of a sample well with a split fabric seal in place of a slotted sample pipe. The installation and use of "controlled" fittings has a negligible effect on the cost of the floating roof. The small additional cost of gaskets and seals (~$200) is offset by the savings from installing a sample well instead of a slotted sample pipe ($100 to $300).[8] Also, "controlled" fittings are not expected to significantly increase operating costs of internal floating roofs. The final alternative costed in Table 8-2 combines all the preceding alternatives. It includes a liquid-mounted primary seal, "controlled" deck fittings and a wiper type secondary deck perimeter seal (secondary seal).

Table 8-3 presents the estimated installed cost of welded contact internal floating roofs (steel pan) with secondary seals. The primary seal included in these cost estimates is a metallic shoe seal, a liquid-mounted resilient tube seal, or a wiper type seal. Vendor quotes for steel pan roofs with each of these seal types were correlated to produce an "average" or "typical" roof cost function (see Table 8-3). The roof is constructed of steel. Larger roof sizes include auxiliary pontoon flotation.

Table 8-4 presents estimates of the installed capital cost of external floating roof tanks. It is important to realize that these costs include the tank shell in addition to the roof. The cost of control over the fixed roof tank baseline costs is the difference between the external floating roof costs (Table 8-4) and the fixed roof tank cost (Table 8-1) for equivalent tank sizes. The tanks costed in Table 8-4 include primary and secondary seal costs. The primary seals are either liquid-mounted or vapor-mounted resilient tube seals. For external floating roof tanks, the location of the primary seal (i.e. vapor- or liquid-mounted) does not significantly affect the roof cost.

The incremental cost of the control alternatives can be approximated from the estimates contained in Tables 8-1 through 8-4. The comparison of control alternative costs, however, must be made for tanks of equivalent diameter or volume. Care must also be taken to ensure that comparisons are made between equivalent types of equipment, i.e., roof cost versus roof cost or tank cost versus tank cost.

Tables 8-5 through 8-13 present the costs of applying Regulatory Alternatives I-V, the external floating roof control options, and the vapor control alternatives to the model terminal and the model producer/consumer facilities. The model plants are discussed in Chapter 6 and described in Appendix D. Although the model plants contain a number of tanks (terminal, 48 tanks; producer/consumer, 11 tanks), the regulatory alternatives affect only a fraction of the respective tank populations. The majority of tanks are exempted on the basis of size and vapor

Table 8-5. COST OF REGULATORY ALTERNATIVE I*
(fourth-quarter 1982 dollars)

Cost parameters	Model terminal	Model producer/ consumer
Capital cost	56,000	15,800
Annualized capital charges	6,580	1,860
Annual taxes, insurance and administration	2,240	630
Operating costs		
Maintenance	2,800	790
Inspection	560	160
Total annualized cost without product recovery credits	12,180	3,440
Total annualized cost with product recovery credits @ $460/Mg	7,530	2,090
Cost effectiveness in dollars per megagram VOC emssions reduction	744	714

*Noncontact internal floating roof with a vapor-mounted primary seal.

Table 8-6. COST OF REGULATORY ALTERNATIVE II*
(fourth-quarter 1982 dollars)

Cost parameters	Model terminal	Model producer/ consumer
Capital cost	56,600	16,000
Annualized capital charges	6,670	1,890
Annual taxes, insurance and administration	2,260	640
Operating costs		
Maintenance	2,830	800
Inspection	570	160
Total annualized cost without product recovery credits	12,330	3,490
Total annualized cost with product recovery credits @ \$460/Mg	7,480	1,610
Cost effectiveness in dollars per megagram of VOC emissions reduction	710	395

*Noncontact internal floating roof with a liquid-mounted primary seal.

Table 8-7. COST OF REGULATORY ALTERNATIVE III*
(fourth-quarter 1982 dollars)

Cost parameters	Model terminal	Model producer/ consumer
Capital cost	56,600	16,000
Annualized capital charges	6,670	1,890
Annual taxes, insurance and administration	2,260	640
Operating costs		
Maintenance	2,830	800
Inspection	570	160
Total annualized cost without product recovery credits	12,330	3,490
Total annualized cost with product recovery credits @ $460/Mg	7,190	533
Cost effectiveness in dollars per megagram of VOC emissions reduction	644	87

*Noncontact internal floating roof with liquid-mounted primary seal and gasketed deck fittings.

Table 8-8. COST OF REGULATORY ALTERNATIVE IV*
(fourth-quarter 1982 dollars)

Cost parameters	Model terminal	Model producer/ consumer
Capital cost	71,830	23,210
Annualized capital charges	9,130	3,050
Annual taxes, insurance and administration	2,870	930
Operating costs		
Maintenance	3,590	1,160
Inspection	720	230
Total annualized cost without product recovery credits	16,310	5,370
Total annualized cost with product recovery credits @ $460/Mg	11,010	2,230
Cost effectiveness in dollars per megagram of VOC emissions reduction	957	326

*Noncontact internal floating roof with liquid-mounted primary seal, secondary seal and gasketed deck fittings.

Table 8-9. COST OF REGULATORY ALTERNATIVE V*
(fourth-quarter 1982 dollars)

Cost parameters	Model terminal	Model producer/ consumer
Capital cost	184,800	90,800
Annualized capital charges	22,400	11,000
Annual taxes, insurance and administration	7,390	3,630
Operating costs		
Maintenance	9,240	4,540
Inspection	1,850	910
Total annualized cost without product recovery credits	40,880	20,080
Total annualized cost with product recovery credits @ $460/Mg	35,500	16,770
Cost effectiveness in dollars per megagram of VOC emissions reductin	3,040	2,330

*Welded contact internal floating roof with liquid-mounted primary seal, secondary seal and gasketed deck fittings.

Table 8-10. COST OF EXTERNAL FLOATING ROOF TANKS WITH PRIMARY SEAL AND SECONDARY SEAL (second-quarter 1982 dollars)

Cost parameters	Model terminal	Model producer/ consumer
Capital cost	150,920[a]	47,210[a]
Annualized capital charges	18,420	5,900
Annual taxes, insurance and administration	6,040	1,890
Operating costs		
Maintenance	7,550	2,360
Inspection	1,500	470
Total annualized cost without product recovery credits	33,510	10,620
Total annualized cost with product recovery credits @ $460/Mg	b	b
Cost effectiveness in dollars per megagram of VOC emissions reduction	b	b

[a] Costs above the baseline control cost.

[b] External floating roofs do not reduce emissions beyond the baseline level. Therefore, no emissions reduction credits exist. Emissions rates for both the model terminal and the model producer/consumer are expected to increase. Consequently, cost effectiveness for the alternative is undefined.

Table 8-11. COST OF EXTERNAL FLOATING ROOF TANKS WITH LIQUID-MOUNTED PRIMARY SEAL AND SECONDARY SEAL (second-quarter 1982 dollars)

Cost parameters	Model terminal	Model producer/ consumer
Capital cost	150,920*	47,210*
Annualized capital charges	18,420	5,900
Annual taxes, insurance and administration	6,040	1,890
Operating costs		
Maintenance	7,550	2,360
Inspection	1,500	470
Total annualized cost without product recovery credits	33,510	10,620
Total annualized cost with product recovery credits @ $460/Mg	29,350	10,400
Cost effectiveness in dollars per ton of VOC emissions reduction	3,250	21,990

*Costs above the baseline control cost.

Table 8-12. COST OF VAPOR CONTROL BY INCINERATION TECHNIQUES
(second-quarter 1982 dollars)

Cost parameters	Model terminal	Model producer/ consumer
Capital cost	631,000[a,b]	631,000[a,b]
Annualized capital charges	114,000	114,000
Annual taxes, insurance and administration	4,100	4,100
Operating costs		
Maintenance	31,600	31,600
Labor	27,200	27,200
Energy	4,900	4,900
Total annualized cost without product recovery credits	181,800	181,800
Total annualized cost with product recovery credits @ $460/Mg	c	c
Cost effectiveness in dollars per megagram of VOC emissions reduction	15,500	20,700

[a] Cost estimates assume one incineration unit and saturator per facility (see Chapter 4).

[b] Based on a first-quarter 1980[4] estimate scaled by a 1.25 factor to reflect second-quarter 1982 prices.

[c] Because there are no recovery credits, the cost is equal to the total annualized cost without product recovery credits.

Table 8-13. COST OF VAPOR RECOVERY BY CARBON ADSORPTION TECHNIQUES (second-quarter 1982 dollars)

Cost parameters	Model terminal	Model producer/ consumer
Capital cost	631,000[a,b]	631,000[a,b]
Annualized capital charges	114,000	114,000
Annual taxes, insurance and Administration	4,100	4,100
Operating costs		
Maintenance	31,600	31,600
Labor	45,000	45,000
Energy	60,000	60,000
Total annualized cost without product recovery credits	255,000	255,000
Total annualized cost with product recovery credits @ $460/Mg	249,600	250,970
Cost effectiveness in dollars per megagrams of VOC emissions reduction	21,280	28,650

[a] Assumes one unit per facility sized for 0.142 standard m^3/s of saturated vapor diluted to 25% LEL for a total of 8.0 standard m^3/s.

[b] Based on a first-quarter 1980 estimate[4] scaled by a factor of 1.25 to reflect second-quarter 1982 prices.

pressure. Four tanks (2 fixed roof and 2 floating roof tanks) are affected by the regulatory alternatives in the model producer/consumer plants. The model terminal has five affected tanks (4 fixed roof and 1 floating roof tank). These tanks can be identified by inspection of Appendix D with an understanding of the baseline control level described in Section 3.3. The base capital cost of all storage vessels at the model terminal is 1.07 million dollars, and the base capital cost of storage vessels at the model producer/consumer plant is 0.25 million dollars. As mentioned previously, these costs do not include foundation costs, land costs or other costs that are not affected by the regulatory alternatives.

The cost of a vapor control system is a function of the vapor flow rate to the system. This flow rate is controlled by the rate at which liquids are pumped into the tank and not by tank diameter or volume. No cost tables are presented for vapor recovery. The capital costs of installing a carbon adsorption or thermal oxidation vapor control system to reduce volatile organic compound (VOC) emissions from the model plants are estimated from information supplied by EPA reports.[1,2] (See Tables 8-12 and 8-13.) It is assumed that each system is sized for a stream of saturated vapor at 0.142 standard cubic meters per second (0.142 standard m^3/s). Because of the large size of the vapor control systems, it is assumed that only one system is needed for each model facility. However, because of product compatibility or operating problems, actual facilities might need more than one unit; therefore, the cost estimates are almost certainly low.

8.2 ANNUALIZED CAPITAL COSTS

The capital cost for each regulatory alternative is annualized assuming the useful equipment lifetimes listed in Table 8-14. In estimating the annualized capital cost for the equipment, it is assumed the capital is borrowed at a 10 percent real interest rate. Based on the estimated equipment lifetimes and the assumed interest rate, annualized capital costs are estimated with the capital recovery factor method.

Table 8-14. LIFETIMES OF CONTROL EQUIPMENT

Device	Lifetime (yrs)	Capital Recovery Factor[a]
Tank and floating roof	20	0.11746
Secondary seals	10	0.16275
Carbon adsorber	10	0.16275
Thermal oxidizer	10	0.16275

[a] Capital recovery factor determined by the equation:

$$CRF = i(1 + i)^n/(1 + i)^n - 1;$$

where i = the annual interest rate and
n = the equipment lifetime.

Table 8-15. COST ANNUALIZING ASSUMPTIONS

Item	Charge
Tax, insurance, and administration	4% of capital cost
Maintenance	5% of capital cost
Inspection	1% of capital cost
Interest rate	10%
Labor	$16/hr
Natural gas	$\$3.00/10^9$ J
Electricity	$0.04/kWh
Energy other than natural gas or electricity	$\$2.50/10^9$ J

8.3 ANNUALIZED COSTS

The annualized cost without product recovery credits is calculated by adding the annualized capital charges to the costs for taxes, insurance and administration (4 percent of the capital costs) and the operating costs. Operating costs include the yearly maintenance charge of 5 percent of the capital cost, and an inspection charge of 1 percent of the capital cost. (See summary in Table 8-15.) The factors used to estimate the cost of taxes and administration (4 percent) and maintenance costs (5 percent) are based on operating experience of the Hydroscience Company.[9]

In respect to vapor control systems, utility expenses are estimated using electricity costs of $0.04 per kilowatt-hour, natural gas costs of $3.00 per 10^9 joules, and other energy costs of $2.50 per 10^9 joules. Emission monitoring costs were included in the annualized estimates for a flame ionization hydrocarbon detector at $4,500, for a flow measurement device at $2,500, and for bottled gas to operate the flame ionization detector at $2,625 per year. These monitoring costs were annualized for a charge of $3,750 per year. Additionally, it is assumed that 500 hours of operating labor at $16 per hour will be required to operate and maintain the emission monitoring system.

The total annualized cost with product recovery credits is calculated by accounting for the value of any recovered product. The recovered product was costed based on a weighted average product value of roughly 100 synthetic organic chemicals. A price of $460/megagram represents the weighted average product value (1978 average scaled to 1982 dollars with a factor of 1.55 based on the Chemical Engineering Journal Industrial Chemical Producer's Price Index). The amount of recovered product was assumed equal to the emissions difference between the baseline emissions and each regulatory alternative, except for thermal oxidation. Because the thermal oxidation unit destroys VOC vapors, no recovery credits were assumed.

8.4 COST EFFECTIVENESS

The cost effectiveness of a regulatory alternative is defined as the cost per metric ton of VOC removed. The average product price of

$460/megagram was used in these calculations to quantify credits for recovered product that would be lost under the baseline conditions. The cost effectiveness values presented in Table 8-5 through 8-13 are in units of dollars per megagram of VOC determined by dividing the total annualized cost by the emission reduction achieved by a regulatory alternative or control technique.

8.5 COST OF OTHER FEDERAL REGULATIONS

There are a wide variety of Federal statutes that affect the manufacture and storage of volatile organic liquids. Table 8-16 lists 12 Federal statutes that control human and environmental exposure to toxic chemicals.[10] The same statutes will also apply to volatile organic liquids (VOLs). Regulatory action required by these statutes controls the chemicals in products and wastes, ambient and occupational environments, chemical identification, chemical sources, and the handling, discharge, and ultimate disposal of chemicals. These regulations will cause an outlay of capital by the chemical manufacturing industry. Total spending for pollution control by the chemical industry in 1979 was expected to be $639 million.[11] Costs to specific segments of the industry, however, are difficult to distinguish on the basis of published data. The costs of the proposed regulations are difficult to estimate because of the lack of available information regarding the content of the final regulations. This section summarizes the available data on costs imposed upon the chemical manufacturing and storage industries by Federal regulations and discusses the impact of these costs on their operations.

Regulatory statutes that apply to manufacturers and users of VOLs are listed in Table 8-17. This list includes the statutes from Table 8-16, in addition to several others, and briefly describes the provisions, requirements, and regulatory concerns of each statute.[12] The last column lists and describes the approximate costs of the statutes. In some cases, this column is blank because relevant cost data could not be found. Most of the costs available are for the general chemical industry and are not subdivided into costs for handlers of VOLs. However, Table 8-17 does show that these costs are considerable. Other indirect costs, such as the "abandonment" of new chemicals, and decreases in

Table 8-16. FEDERAL LAWS REGULATING TOXIC CHEMICALS

Title	Abbreviation	Public Law No.
Toxic Substance Control Act of 1976	TSCA	94-469
Food, Drug, and Cosmetic Act, as amended in 1976	FDCA	94-295
Occupational Safety and Health Act of 1980	OSHA	91-596
Consumer Product Safety Act of 1970	CPSA	92-573
Marine Protection, Research and Sanctuaries Act of 1972	Ocean Dumping	92-532
Federal Pesticide Act of 1978	FPA	95-396
Clean Air Act, as amended in 1977	CAA	95-95
Federal Water Pollution Control Act, amended as Clean Water Act of 1977	FWPCA CWA	92-500 95-217
Safe Drinking Water Act of 1974	SDWA	93-523
Resource Conservation and Recovery Act of 1976	RCRA	94-580
Hazardous Materials Transportation Act of 1970	HMTA	91-458
National Environmental Policy Act of 1969	NEPA	91-190

Table 8-17. STATUTES THAT MAY BE APPLICABLE TO THE MANUFACTURE AND STORAGE OF VOLATILE ORGANIC LIQUIDS

Statute	Applicable provision, regulation, or requirement of statute	Approximate costs incurred
Toxic Substances Control Act	• Premanufacture notification • Labelling, recordkeeping • Reporting requirements • Toxicity testing	• General reporting rule (Section 8(a)) is expected to initially cost chemical manufacturers about $6 million. EPA estimates the cost will be $420 for each chemical a manufacturer produces.[16] • Costs for entire chemical industry projected to be $100-200 million per year. Preinventory notification cost: $1,200-1,500 per chemical.[17]
Food, Drug, and Cosmetic Act	• Consumer use of chemicals	
Occupational, Safety, and Health Act	• Walking-working surface standards • Means of egress standards • Occupational health and environmental control standards • Hazardous material standards • Personal protective equipment standards • General environmental control standards • Medical and first aid standards • Fire protection standards • Compressed gas and compressed air equipment • Welding, brazing, and cutting standards	• $220/year per worker.[18]
Consumer Product Safety Act	• Consumer use of chemicals	
Marine Protection, Research and Sanctuaries Act	• Ocean dumping permits • Recordkeeping and reporting	
Federal Pesticide Act	• Consumer use of chemicals	• About $256 million lost due to cancellation or suspension of pesticides.[19]
Clean Air Act and Amendments	• State Implementation Plans • National Emission Standards For Hazardous Air Pollutants • New source performance standards: Air oxidation Volatile organic liquid storage • PSD construction permits • Nonattainment construction permits	• About $249 million spent by entire chemical industry for air pollution control.[14]

(continued)

Table 8-17. Concluded

Statute	Applicable provision, regulation or requirement of statute	Approximate costs incurred
Clean Water Act	• Discharge permits • Effluent limitations guidelines • New source performance standards • Control of oil spills and discharges • Pretreatment requirements • Monitoring and reporting • Permitting of industrial projects that impinge on wetlands or public waters • Environmental impact statements	• Increased annual costs to pesticide manufacturers, caused by regulations, under Sections 301 and 304, would range between 0.2 and 2 percent of the revenues from pesticide chemicals. Profitability would be reduced for some manufacturers.[20] • Total annual cost of $243 million incurred by organic chemical, pesticide, and explosives industries to comply with EPA hazardous waste regulations.[15] • Another source estimates $414 million total expenditure by entire chemical industry for water pollution control.[14]
Safe Drinking Water Act	• Requires underground injection control permits	
Resource Conservation and Recovery Act	• Permits for treatment, storage, and disposal of hazardous liquids. • Establishes system to track hazardous wastes • Establishes recordkeeping, labelling, and monitoring system for hazardous wastes • Superfund	• Only one out of the more than 500 surface dumps and landfills would meet RCRA standards. Over $1 billion needed to upgrade the others.[22,22] • Proposed that $400 million of $6 billion superfund come from annual industry fees on oil, chemical, and heavy metal industries.[23] Part of fund would come from fee, not to exceed $5 per ton on chemicals. Fund applies only to past disposal practices. • Waste disposal costs are expected to rise from $1.50-$5.00 per ton to over $50 per ton under RCRA.[24]
Hazardous Materials Transportation Act		
National Environmental Policy Act	• Requires environmental impact statements	
Coastal Zone Management Act	• Allows states to veto Federal permits for plants to be sited in coastal zones	
Power Plant and Industrial Fuel Use Act	• Prohibits new, major, industrial power plants, which utilize fuel oil or natural gas	

innovation, productivity, job opportunities, and "incentive for entrepreneurial initiative," are not easily quantified and are excluded.[13,14] In addition, health and economic benefits of the regulations are not considered.[15]

The economic impact of these regulations on the chemical industry is not fully quantified. The Council on Environmental Quality reported in 1979 that the economic health of this industry is better than most and that few plant closings are expected solely because of the costs of compliance with standards and regulations.[25] A 1978 study by EPA's Office of Solid Waste Management found, with regard to regulations concerning hazardous wastes, that "certain individual segments of the industry will be subject to more severe impacts than the industry as a whole, but no plant closures will result directly from the regulations."[26] In contrast, a survey sponsored by the Chemical Specialties Manufacturers Association reported that 14 percent of the firms surveyed said that present and upcoming EPA regulations could cause them to close. Nine percent said that EPA rules could cause a change of ownership. The survey stressed that the greatest difficulty caused by the regulations would be increased operating costs, followed by reporting and recordkeeping requirements and increased capital costs.[13] Part of this discrepancy in the perceived impact of Federal regulations may be reduced through the efforts of the Interagency Regulatory Liaison Group (IRLG). The IRLG intends to strongly emphasize the coordination of regulations being developed by member groups and will also emphasize the economic analysis of the proposed regulations. Agencies participating in the IRLG include EPA, the Occupational Safety and Health Administration, the Consumer Product Safety Commission, the Food and Drug Administration, and the Food Safety and Quality Service.[27]

A list of currently proposed regulations that will affect the chemical industry is given in Table 8-18.[28] The economic impact of these regulations will be unclear until their final forms are determined from a number of regulatory alternatives. Studies of the economic effects of many of these regulations are underway at this time.

Table 8-18. PROPOSED REGULATIONS THAT WILL AFFECT THE CHEMICAL MANUFACTURING INDUSTRY (as listed in the Calendar of Federal Regulations)

Agency	Title of regulation	Page No. in calendar
DOL-OSHA	Chemical Warning Systems	68278
DOL-OSHA	Safety standard for walking and working surfaces	68283
EPA-OANR	National Emission Standards for Hazardous Air Pollutants – Benzene	68239
EPA-OANR	Policy and Procedures for Identifying, Assessing, and Regulating Airborne Substances Posing a Risk of Cancer	68292
EPA-OANR	Regulations for the prevention of significant deterioration resulting from hydrocarbons for carbon monoxide, nitrogen oxides, ozone, and lead	68244
EPA-OPTS	Rules and notice forms for premanufacture notification of new chemical substances	68294
EPA-OPTS	Standards and Rules for Testing of Chemical Substances and Mixtures	68297
EPA-OWWM	Hazardous waste regulations: Core regulations to control hazardous solid waste from generation to final disposal	68299

8.6 COSTS AND COST EFFECTIVENESS OF CONTROLS ON AN INDIVIDUAL TANK

This section presents the costs and cost effectiveness of controlling an individual tank. The tank selected for analysis is the model tank presented in Chapter 4, Section 1. Emissions from the possible configurations of the model tank are presented in Table 4-2. The capital and annualized cost (without product recovery credits) of controls are presented in Table 8-19. Both the absolute cost effectiveness and the incremental cost effectiveness will be discussed.

The absolute cost effectiveness is defined as the total annualized cost of a particular control option minus the value of product recovery credit (the difference yielding the net annualized cost), divided by the total emissions reduction achieved by going from no control to that control option. Incremental cost effectiveness is defined as the difference in net annualized cost between two control options, divided by the difference in emission reduction between the same two options.

Table 8-20 presents the absolute cost effectiveness of building the model tank as a new internal floating roof tank in place of a fixed roof tank. Table 8-21 presents the incremental cost effectiveness of controlling seal emissions from an internal floating roof. Table 8-22 presents the incremental cost effectiveness of controlling deck seam emissions by the use of welded decks. Consistent with the assumption used previously in this chapter, the cost of controlling fittings is assumed to be zero; the cost effectiveness of these controls is, therefore, zero. Based on the above information, Table 8-23 presents the incremental cost effectiveness between the regulatory alternatives. Because it is possible to replace a fixed roof tank with an external floating roof, an analysis of the internal floating roof equipment requirements of the regulatory alternatives was made relative to an external floating roof tank with a mechanical shoe seal and a secondary seal. Table 8-24 presents the incremental cost effectiveness of building the model tank as an external floating roof tank with a mechanical shoe primary seal and a secondary seal instead of the equipment required by each regulatory alternative.

Table 8-19. CAPITAL AND ANNUALIZED COSTS FOR BASELINE AND CONTROL EQUIPMENT FOR THE MODEL VOL TANK

Item	Capital Cost ($)	Annualized Cost ($)
1. Fixed roof tank	35,600	7,750
2. External floating roof tank with mechanical shoe primary seal only	52,900	11,500
3. Bolted deck	10,700	2,330
4. Welded deck	25,100	5,460
5. Secondary seal for internal or external floating roof tank	2,440	640
6. Liquid-mounted primary seal	75	17

Table 8-20. ABSOLUTE COST EFFECTIVENESS OF CONTROLLING FIXED ROOF TANK EMISSIONS FROM THE MODEL TANK

Tank Type/Equipment	Emissions (Mg/yr)	Cost Effectiveness ($/Mg)
I. Fixed roof tank	6.22	–[1]
II. Internal floating roof tank		
A. Bolted deck, vapor-mounted primary seal, uncontrolled fittings	0.41	41
B. Bolted deck, liquid-mounted primary seal, uncontrolled fittings	0.34	39
C. Bolted deck, liquid-mounted primary seal, controlled fittings	0.24	32
D. Bolted deck, liquid-mounted primary seal and secondary seal, controlled fittings	0.21	137
E. Welded deck, liquid-mounted primary seal and secondary seal controlled fittings	0.17	650
III. External floating roof tank with mechanical shoe primary seal and secondary seal	0.068	390

[1] Not applicable.

Table 8-21. INCREMENTAL COST EFFECTIVENESS BETWEEN INTERNAL FLOATING ROOF SEAL TYPES IN THE MODEL TANK

Base Case	End Case		
	Vapor-mounted with Secondary	Liquid-mounted	Liquid-mounted with Secondary
	($/Mg)	($/Mg)	($/Mg)
Vapor-mounted	7,640	credit	6,840
Liquid-mounted	_[1]	_[1]	23,400

[1] Not applicable.

Table 8-22. INCREMENTAL COST EFFECTIVENESS OF CONTROLLING DECK SEAM EMISSIONS IN THE MODEL TANK

Base Case	End Case	Incremental Cost Effectiveness ($/Mg)
Bolted deck	Welded deck	77,900

Table 8-23. REGULATORY ALTERNATIVES AND INCREMENTAL COST EFFECTIVENESS ($/Mg) BETWEEN REGULATORY ALTERNATIVES IN THE MODEL TANK

Regulatory Alternative									
0	($/Mg)	I	($/Mg)	II	($/Mg)	III	($/Mg)	IV	($/Mg)	V
FR —[2]	41 →	$b^{IFR}{}_{vm}$	credit →	$b^{IFR}{}_{lm}$	0 →	$b^{IFR}{}_{lm,cf}$ →	23,400	$b^{IFR}{}_{lm,ss,cf}$ →	77,900	$w^{IFR}{}_{lm,ss,cf}$

[1] Notation is as follows:

FR = fixed roof tank
IFR = internal floating roof tank
b = bolted deck
w = welded deck
lm = liquid-mounted primary seal
vm = vapor-mounted primary seal
ss = secondary seal
cf = controlled fittings

[2] No controls required.

Table 8-24. INCREMENTAL COST EFFECTIVENESS BETWEEN EQUIPMENT SPECIFIED BY EACH REGULATORY ALTERNATIVE AND AN EXTERNAL FLOATING ROOF TANK WITH A MECHANICAL SHOE SEAL AND A SECONDARY SEAL

Regulatory alternative as base case			
Number	Equipment[1]	Emission reduction (Mg)	Cost effectiveness (\$/Mg)[2]
0	FR	6.15	390
I	${}_{b}\mathrm{IFR}_{vm}$	0.34	5,700
II	${}_{b}\mathrm{IFR}_{lm}$	0.27	7,210
III	${}_{b}\mathrm{IFR}_{lm,cf}$	0.17	11,700
IV	${}_{b}\mathrm{IFR}_{lm,ss,cf}$	0.14	9,660
V	${}_{w}\mathrm{IFR}_{lm,ss,cf}$	0.10	NA[3]

[1] Notation is as follows:

FR = fixed roof tank
IFR = internal floating roof tank
EFR = external floating roof tank
b = bolted deck
w = welded deck
lm = liquid-mounted primary seal
vm = vapor-mounted primary seal
ms = mechanical shoe primary seal
ss = secondary seal
cf = controlled fittings

[2] The annualized cost without product recovery credit is calculated as follows:

Annualized cost = (cost of external floating roof tank + cost of secondary seal) - (cost of fixed roof tank + cost of controls).

[3] Regulatory Alternative V is more expensive than the $\mathrm{EFR}_{ms,ss}$ control option. Therefore, cost effectiveness is undefined.

8.7 REFERENCES

1. Basdekis, H. S. Emissions Control Options for the Synthetic Organic Chemicals Manufacturing Industry; (draft document submitted to EPA). Hydroscience, Inc. Knoxville, Tennessee. February 1980. 100 p.

2. Blackburn, J. W. Emissions Control Options for the Synthetic Organic Chemicals Manufacturing Industry; (draft document submitted to EPA). Hydroscience, Inc. Knoxville, Tennessee. December 1979. 120 p.

3. Memoranda from Shumaker, J.L. to Moody, W. of TRW Environmental Protection Agency, dated October 11, 1982. Summarizing cost data from 11 equipment manufacturers and the correlation of data into general equipment cost equations.

4. "Economic Indicators" Chemical Engineering, May 19, 1980, January 22, 1980, and October 4, 1982.

5. Telecon. Hyatt, Terry, Pittsburgh, Des Moines with Rockstroh, Margaret, TRW. May 19, 1980. Costs of cone roof tanks, external floating-roof tanks, and secondary seals.

6. Letter from Rutland, McBarnett, GATX, to Guidetti, R., TRW. December 3, 1979. Costs for external floating-roof tanks and cone roof tanks.

7. Telecon. Stilt, George, Pittsburgh Des Moines with May, George, TRW. April 10, 1980. Costs of external floating roof tanks and secondary seals.

8. Memorandum regarding internal floating roof deck fittings costs from J. Shumaker to W. Moody, TRW Environmental Division, Research Triangle Park, NC. November 8, 1982.

9. Erickson, D. G. Draft Storage and Handling Report; Emission Control Options for the Synthetic Organic Chemicals Manufacturing Industry. Hydroscience, Inc. prepared for the U.S. Environmental Protection Agency, Research Triangle Park, NC. Contract No. 68-02-2577. October 1978.

10. Unit Process Guide to Organic Chemical Industries, Vol. 1. Science Publishers, Inc. Ann Arbor, Michigan.

11. News Flashes. Chemical Engineering. 86:12. 1979. p. 77.

12. U.S. Environmental Protection Agency. VOC Fugitive Emissions in Synthetic Organic Chemicals Manufacturing Industry - Background Information for Proposed Standards; (Preliminary draft). Research Triangle Park, North Carolina. March 1980. p. 8-25, 8-26.

13. Chemical Specialties Manufacturers Cite EPA as Having Biggest Economic Effect. Chemical Regulation Reporter. November 2, 1979. p. 1317.

14. Jellinek Says EPA Will Use Authority to Compel Disclosure of PMN Information. Chemical Regulation Reporter. January 11, 1980. p. 1586.

15. Nader Group Scores Industry Figures on Costs, Benefits of Health Regulations. Chemical Regulation Reporter. October 12, 1979. p. 1107.

16. EPA Estimates TSCA Reporting Role Would Cost Chemical Industry $6 Million. Chemical Regulation Reporter. Bureau of National Affairs, Inc. January 11, 1980. p. 1585.

17. Proprosal of Premanufacture Notification Notice Form and Provision of Rules 40 CFR, Part 720.44(201). Washington, D.C. U.S. Government Printing Office. October 16, 1979.

18. Arthur Anderson and Co. Cost of Government Regulation Study. Washington, D.C. March 1979.

19. Cost of Pesticide Cancellations, Suspensions "Nominal," EPA Report Says. Chemical Regulation Reporter. February 29, 1980. p. 1794.

20. EPA Water Act Regulations for Pesticide Industry Upheld. Chemical Regulation Reporter. May 18, 1979. p. 220-221.

21. RCRA Waste Disposal Discussed. Chemical Regulation Reporter. April 27, 1979. p. 93.

22. Union Carbide Sees $2 Billion Price to Upgrade Storage Ponds Under RCRA. Chemical Regulation Reporter. April 27, 1979. p. 98.

23. Government Considers $6 Billion Fund. Chemical Regulation Reporter. May 4, 1979. p. 119.

24. Disposal Costs for Handling Wastes Outlined by Consultant at Conference. Chemical Regulation Reporter. September 21, 1979. p. 982.

25. Environmental Quality, The Ninth Annual Report of the Council on Environmental Quality. Council on Environmental Quality. Washington, D.C. December 1978.

26. Study Reports Costs of Complying with Anticipated EPA Regulations. Chemical Regulation Reporter. 1978. p. 272.

27. Economic Analyses, Coordination to be Emphasized by IRLG in 1980-1981. Chemical Regulation Reporter. January 11, 1980. p. 1590.

28. Calendar of Federal Regulations. Federal Register, 44:230. November 29, 1979.

9. ECONOMIC IMPACT

9.1 INDUSTRY PROFILE

9.1.1 Introduction

This industry profile describes the economic characteristics of industries that store volatile organic liquids (VOLs) in order to provide background information necessary to formulate and execute the economic impact analysis of Subsection 9.2. Discussion begins by identifying and describing industries of interest: those involved in VOL production, VOL consumption, and VOL storage at merchant terminals. Historic information on the basic supply and demand conditions of these industries, including production and sales levels and inputs into their production activities, is presented in the basic conditions subsection. Three subsections are devoted to a discussion of the structure, conduct, and performance of firms in the three industry segments of interest.* The profile concludes with a presentation of the methodology and results for projecting the nationwide VOL storage tank population for the 1984 to 1988 period.

9.1.2 Identification and Description of VOL-Storing Industries

9.1.2.1 VOL Producers. Figure 9-1 is a flow chart of the organic chemicals industry from raw feedstocks to end products. Many industry segments identified in Figure 9-1 store VOLs or contract for VOL storage: primary organic chemical manufacturers may handle VOL inputs and outputs, and many organic chemical products use VOLs as a principal material input or as an important component of the manufacturing process; e.g., solvents used in the manufacture of textiles. This industry is complex because many chemicals it manufactures subsequently are used within the industry to produce other organic chemicals. Hegman, for example, estimates that intraindustry shipments constitute as much as two-thirds of total sales in the organic chemical industry.[2] This phenomenon frequently results in double counting of the

---

*For a definition and discussion of these terms and their role in economic analysis, see Reference 1.

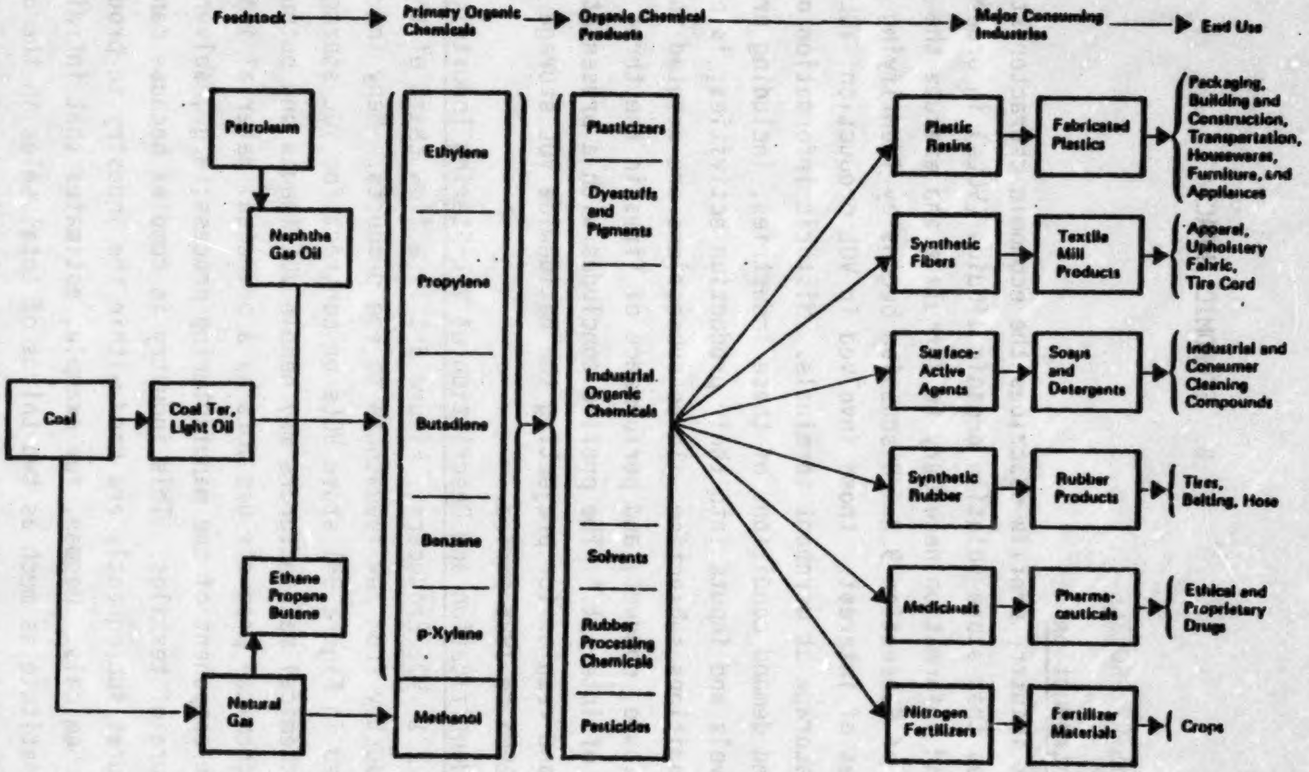

Feedstock
Primary Organic Chemicals
Organic Chemical Products
Major Consuming Industries
End Use
Petroleum
Naphtha Gas Oil
Coal
Coal Tar, Light Oil
Ethane Propane Butane
Natural Gas
Ethylene
Propylene
Butadiene
Benzene
p-Xylene
Methanol
Plasticizers
Dyestuffs and Pigments
Industrial Organic Chemicals
Solvents
Rubber Processing Chemicals
Pesticides
Plastic Resins
Synthetic Fibers
Surface-Active Agents
Synthetic Rubber
Medicinals
Nitrogen Fertilizers
Fabricated Plastics
Textile Mill Products
Soaps and Detergents
Rubber Products
Pharmaceuticals
Fertilizer Materials
Packaging, Building and Construction, Transportation, Housewares, Furniture, and Appliances
Apparel, Upholstery Fabric, Tire Cord
Industrial and Consumer Cleaning Compounds
Tires, Belting, Hose
Ethical and Proprietary Drugs
Crops

Figure 9-1. Organic chemical industry flow chart.[2]

output of primary and intermediate chemicals and hampers accurate measurement of production and sales.

Manufacturers of VOLs are classified in the three-digit standard industrial classification (SIC) code 286, Industrial Organic Chemicals. This category also includes establishments primarily engaged in the manufacture of some nonvolatile and solid chemicals. For example, SIC 286 includes establishments primarily engaged in the manufacture of fabricated rubber and explosives.

While establishments primarily engaged in the manufacture of industrial organic chemicals are classified in SIC 286, establishments classified in other SIC industries produce these chemicals as secondary products. Approximately 20 percent of all industrial organic chemicals are produced in establishments not classified in SIC 286.[3]

9.1.2.2 VOL Consumers. Industries in SIC 28, Chemicals and Allied Products, consume the largest amount of VOLs. The largest consuming industry is also the producing industry: SIC 286, Industrial Organic Chemicals. Other important consuming industries are SIC 282, Plastics Materials and Synthetics; SIC 283, Drugs; SIC 284, Soaps, Cleaners, and Toilet Goods; and SIC 287, Agricultural Chemicals. Booz, Allen, and Hamilton, Inc., conducted a survey of organic emissions to identify which consuming industries store significant amounts of VOLs. The survey indicates that industrial organic chemical producers, who in most cases are also VOL consumers, accounted for 64 percent of VOL emissions from storage tanks.[4] It also indicates that an additional 20 percent of all VOL emissions from storage tanks within the chemical industry originated in SIC 282, Plastics Materials and Synthetics. Other consuming industries each generate less than 5 percent of storage tank emissions and are not considered further here.

Flows of industrial organic chemicals are traced from SIC 286, Industrial Organic Chemicals, to other industries, based on U.S. Department of Commerce 1972 input/output tables.[5]* Major consumers of industrial organic chemicals not included in SIC 28 are SIC 22, Textile Mill Products; SIC 30, Rubber and Miscellaneous Plastics Products; and SIC 24, Lumber and Wood Products. The major types of chemicals provided to these users are dyes, lakes, toners, creosote oil, rubber-processing chemicals, and plasticizers. Shipments of these products amounted to $701 million in 1972, or about 6.1 percent of total industry shipments from SIC 286.[6] Because the amount is so small, storage of chemicals outside of SIC 28 has been disregarded.

---

*Industrial organic chemicals are included in two input/output commodity groups: Industrial Organic and Inorganic Chemicals, and Gum and Wood Chemicals. The commodity-by-commodity input/output table lists the percentage of total U.S. output of the above chemicals consumed by producers of other commodities. Any commodity that accepted 1 percent or more of the flow of output of either industrial organic and inorganic chemicals or gum and wood chemicals was included in the 1972 Census of Manufactures under the appropriate industry group. Data on consumption of industrial organic chemicals appear in the input/output table on materials consumed by kind.

Another user of industrial organic chemicals is SIC 516, Wholesale Trade of Chemicals and Allied Products, whose establishments purchase chemicals for repackaging and reselling. Industry contacts indicate that the storage tanks used by these distributors typically have less than 75 m^3 capacity.[7] Because this capacity is less than the cutoffs considered under each regulatory alternative, this profile does not include wholesale distributors.

9.1.2.3 VOL Storage Terminals. Data on storage services are difficult to collect for three reasons. First, most of the small private-merchant terminals that store VOLs do not report financial data publicly. Second, many of the larger publicly traded companies aggregate data on chemical storage services with data from other accounting units or with data from storage of other commodities, making it impossible to assess the financial and economic performance of VOL storage enterprises. Third, government publications do not present data on storage in a specific SIC code. Data on chemical storage services are included in SIC 4226, Special Warehousing and Storage Not Elsewhere Classified, along with data on merchant warehousing of other commodities such as petroleum, whiskey, and furs. Thus, data reported for this category in the 1972 Census of Business Services do not represent chemical storage services as such. Furthermore, because establishments are classified by their primary functions and because chemical storage is usually a secondary function, data on much of the chemical storage industry are contained in SIC industry categories other than SIC 4226. Proprietary or captive terminals, if used as storage points rather than as wholesale distribution centers, are classified as auxiliary establishments for which no revenues or other statistics are reported.

For this report, information on bulk chemical storage was obtained from a trade association, the Independent Liquid Terminals Association (ILTA). Members of this organization range from a merchant terminal operator with 1 terminal comprised of 7 tanks to an operator with 14 terminals and a total of

1,469 tanks. Few terminal operators report revenues or other statistics and, of those who do, statistics for chemical storage are combined with statistics for other operations.[8] For specific information, nine liquid terminal operators were contacted. No statistics were collected on proprietary terminals.

9.1.3 Basic Conditions

This section addresses supply conditions, which are determined largely by technological considerations, and demand conditions, which depend primarily on product attributes.

9.1.3.1 Supply Conditions. Employment, assets, and costs of materials for industrial organic chemical production (SIC 286) between 1972 and 1977 are provided in Table 9-1. Total employment in the industrial organic chemical industry increased about 12 percent over this 5-year period. Assets also have increased since 1972. Expenditures on materials have tripled, largely because of the increased cost of petroleum-based raw materials.

Resource use in Plastics Materials and Synthetics (SIC 282) is presented in Table 9-2. In contrast to the industrial organic chemical industry, this industry is becoming more capital intensive. Total employment fell by almost 3 percent between 1972 and 1977, and the number of production workers declined by over 4 percent. Over roughly the same period, value of assets increased 38 percent. Between 1972 and 1977, expenditures on materials increased dramatically, by over 130 percent, primarily because of increased fuel and feedstock prices.

Capital expenditures and operating rates for the VOL-producing and VOL-consuming industries are presented in Table 9-3, in both current and constant dollars, for the years 1958 to 1978. Expenditures by VOL producers declined for some years prior to 1972. When oil prices increased sharply in 1973, expenditures started to grow again in real terms, rising by almost 200 percent over 5 years. A trade survey indicated that these new expenditures were for improvements in old plants and process efficiency gains rather than for new capital assets.[9] Capital expenditures in SIC 282, Plastics Materials and Synthetics, have increased steadily since 1958 as demand for plastics has grown. The most dramatic growth occurred after 1973, when plastics and resins companies began large expansion programs, after which expenditures declined as companies invested in process improvements.

TABLE 9-1. RESOURCE USE BY PRODUCERS OF INDUSTRIAL ORGANIC CHEMICALS (SIC 286)[10]

Year	Employment (10^3)	Production workers (10^3)	Cost of materials[a,b] ($\$10^6$)	Assets[a,b] ($\$10^6$)
1972	136.5	87.9	5,514.4	12,490.9
1973	137.8	89.2	6,488.4	13,258.9
1974	135.2	88.2	10,608.8	14,068.3
1975	137.3	86.4	11,765.7	16,360.3
1976	141.8	90.3	14,713.9	18,972.9
1977	152.8	97.9	17,607.7	N/A

[a] Current dollars.

[b] The adjective "current" or "nominal" describes the measurement of an economic magnitude in current prices; i.e., prices pertaining to the year in question. When current or nominal values are compared for different years, no account is taken of general price inflation or deflation. By contrast, the adjective "real" or "constant" refers to attempts to measure economic magnitudes by the quantity of real goods and services they command; i.e., with the general rate of inflation deducted to record the real command over resources.

TABLE 9-2. RESOURCE USE BY PRODUCERS OF PLASTICS MATERIALS AND SYNTHETICS (SIC 282)[10]

Year	Employment (10^3)	Production workers (10^3)	Cost of materials[a] ($\$10^6$)	Assets[a] ($\$10^6$)
1972	161.9	116.0	4,854.9	9,468.5
1973	164.1	118.6	5,310.6	10,090.6
1974	169.8	121.8	8,521.9	11,268.3
1975	150.3	104.0	8,591.7	12,220.3
1976	152.8	107.0	10,687.5	13,047.7
1977	157.1	111.1	11,552.6	N/A

[a] Current dollars.

TABLE 9-3. CAPITAL EXPENDITURES AND OPERATING RATES FOR SIC 286 AND SIC 282, 1958 to 1978

	Implicit price deflator, gross private fixed investments nonresidential[a]	Capital expenditures ($10^6)				Operating rates for SIC 28, percentage of nameplate capacity[d]
		SIC 286		SIC 282		
		Current dollars[b]	Constant dollars (1972)[c]	Current dollars[b]	Constant dollars (1972)[c]	
1958	70.6	413.2	585.3	112.3	159.1	--
1959	72.0	314.0	436.1	91.2	126.7	--
1960	72.2	405.9	562.2	147.0	203.6	--
1961	71.8	457.2	636.8	206.8	288.0	--
1962	72.3	353.4	488.8	186.9	258.5	--
1963	72.9	513.4	704.3	240.7	330.2	--
1964	73.6	738.0	1,002.7	270.6	367.7	--
1965	74.5	737.5	989.9	472.0	731.8	--
1966	76.8	981.2	1,277.6	515.8	671.6	--
1967	79.3	937.9	1,182.7	436.5	550.4	--
1968	82.6	997.8	1,208.0	381.0	461.3	85
1969	86.6	861.4	994.7	409.0	472.3	84
1970	91.3	1,030.2	1,128.4	396.7	434.5	80
1971	96.4	949.5	985.0	453.5[e]	470.4[e]	81
1972	100.0	831.6	831.6	693.9[e]	693.9[e]	85
1973	103.8	1,005.6	968.8	829.8	799.4	88
1974	115.3	1,689.4	1,465.2	1,327.4	1,151.3	81
1975	132.3	2,119.8	1,602.3	1,439.5	1,088.1	78
1976	138.7	2,684.4	1,935.4	1,368.6	986.7	78
1977	146.0	3,510.9	2,404.7	1,271.0	870.5	76
1978	--	--	--	--	--	83

---

[a] Reference 11.
[b] References 12, 10.
[c] Constant dollars calculated by dividing current dollars by the price deflator and multiplying by 100.
[d] Reference 13.
[e] Beginning in 1972, a category (Plastics Materials) was reclassified into SIC 282, causing the series prior to 1972 to be inconsistent with the series from 1972 to 1977.

9.1.3.2 Demand Conditions.

9.1.3.2.1 VOL producers and consumers. Demand for VOL storage services depends upon demand for VOL chemicals and upon the inventory and distribution practices of VOL producers and consumers. VOL producers and consumers choose to hold inventories, onsite or in terminals, to facilitate production and sales; i.e., they accept the cost of holding some VOL inventory in exchange for improved operating productivity and sales. For both producers and consumers, inventories are held in bulk due to economies of scale in storage.

Table 9-4 presents data on production and sales of industrial organic chemicals for the period 1955 to 1981. Production of industrial organic chemicals increased at an average annual rate of 6 percent from 1955 to 1974. However, following the sharp rise in oil prices in 1974 and the decreasing demand for chemicals during the 1975 recession, 1975 production declined to 85 percent of the previous year's output. Production declined again slightly in 1976 as producers and consumers both tried to reduce inventories. With economic recovery, production of industrial chemicals increased, rising to 90 percent of the 1974 output in 1978 and surpassing the 1974 level thereafter.

Sales measured in physical units followed a similar pattern, increasing at a 6 percent average annual growth rate from 1955 to 1973. However, rapidly increasing feedstock prices in 1974 resulted in higher chemical prices. In 1975, the volume of sales in physical units dropped to 80 percent of 1973 levels, as the impact of higher real prices was compounded by the 1975 recession. Sales in physical units further declined in 1976 to 77 percent of their 1973 level, began to grow again in 1977, and rose in 1978 to 83 percent of the 1973 peak. The 1973 peak was matched in 1979, but sales in physical units weakened again in 1980 and 1981. Sales in physical units of industrial organic chemicals consistently have represented about 50 percent of production over the period 1955 to 1978. The other 50 percent is captively consumed.

Between 1973 and 1981, current dollar sales increased much more rapidly than did output and volumes of sales in physical units. In some years, dollar sales increased as chemical prices rose even though production and volumes of sales in physical units decreased. Dollar sales increased over 50 percent in 1974, while the volume of sales in physical units fell 3.7 percent. Revenues changed very little as the volume of sales in physical units fell sharply between 1974 and 1975. In 1976, dollar sales began to grow again.

TABLE 9-4. HISTORICAL PRODUCTION AND SALES OF INDUSTRIAL ORGANIC CHEMICALS, 1955 to 1981[14][a]

Year	Production[b] (10^6 Mg)	Sales in physical units[b] (10^6 Mg)	Ratio of sales in physical units to production	Dollar sales[b,c] (\$$10^6$)
1955	23.5	11.9	50.6	2,811
1956	27.8	12.6	45.3	3,009
1957	26.7	12.7	47.6	3,097
1958	24.9	11.9	47.8	3,039
1959	25.0	12.3	49.2	3,498
1960	27.1	12.9	47.6	3,672
1961	27.6	13.4	48.6	4,040
1962	30.1	14.2	47.2	4,082
1963	32.5	15.1	46.5	4,210
1964	36.3	17.5	48.2	4,697
1965	40.1	19.0	47.4	5,182
1966	44.3	20.8	46.9	5,762
1967	45.7	21.7	47.5	6,359
1968	51.4	24.7	48.0	7,047
1969	56.8	27.4	48.6	7,277
1970	57.8	28.1	47.5	7,381
1971	57.7	28.6	46.3	7,592
1972	65.6	33.3	50.8	8,558
1973	69.9	36.2	51.8	10,049
1974	71.8	34.9	48.6	15,245
1975	61.0	29.0	47.5	15,355
1976	61.9	27.9	45.1	16,455
1977	61.2	29.1	47.5	17,945
1978	64.6	30.0	46.4	19,397
1979	82.1	36.3	44.2	26,007
1980	77.8	34.9	44.9	29,057
1981	77.5	33.8	43.6	30,995

---

[a] These data reflect some double counting due to the intraindustry trade already noted.

[b] These figures are developed by aggregating data in the following International Trade Commission industrial categories: tar, tar crudes, cyclic intermediates, dyes, lakes and toners, flavor and perfume materials, rubber-processing chemicals, plasticizers, pesticides, miscellaneous end-use chemicals, and miscellaneous cyclic and acyclic chemicals. Prior to 1975, data on chemicals in the latter category were reported as Miscellaneous Synthetic Organic Chemicals. Figures for 1976 through 1978 are not strictly comparable to figures for other years due to a change in one product classification. The original classification was restored in 1979.

[c] Dollar sales are in current dollars.

Table 9-5 contains production and sales data for plastics and resin materials, the largest VOL consumer. From 1955 to 1973, production and sales in physical units grew at an annual average of over 10 percent. In 1974, sharply rising prices for raw materials reduced output by 15 percent although the volume of sales in physical units grew by over 11 percent. In 1975, sales in physical units fell by 30 percent as price increases and the 1975 recession sharply reduced demand for plastics and resins. Manufacturers reduced 1975 production by only 3.6 percent, however, allowing inventories to increase. In 1976, the volume of sales in physical units increased again as general economic activity in the United States began to rise. Sales in physical units continued to grow in 1977 and exceeded the previous (1974) peak level from 1978 through 1981.

Dollar sales of plastics and resins grew 14.3 percent annually between 1975 and 1978 as producers of automobiles and other durable goods, responding to rising energy prices, sought to replace heavier materials (e.g., steel and glass) with lighter weight plastics. Although prices of plastics and resins also increased, potentially adverse impacts of those price increases on demand for these materials were offset by sharply rising prices for substitute commodities, steel and glass, which are also manufactured by energy-intensive production processes. The combined effect of the increased volume of sales in physical units and rising prices substantially increased dollar sales between 1974 and 1981.

International trade is another potentially important demand component. Specific data on import and export of VOLs are not available. The following discussion therefore presents international trade data for Industrial Organic Chemicals (SIC 286) and Plastics Materials and Synthetics (SIC 282). International trade data on tank storage services are also unavailable.

Table 9-6 presents data on exports and imports of industrial organic chemicals for the years 1972 to 1981. Comparing these data to dollar sales data indicates that a substantial and, over this time period, growing portion of sales is for export. Imports of industrial organic chemicals have been growing at about the same rate as have industry sales but are much smaller than the level of exports, so trade in industrial organic chemicals has contributed favorably to the U.S. balance of trade.

Table 9-7 presents data on exports and imports of plastics materials and synthetics. These data also indicate a favorable balance of trade. Growth in

TABLE 9-5. HISTORICAL PRODUCTION AND SALES OF PLASTICS AND RESIN MATERIALS, AND ELASTOMERS, 1955 to 1981[14] [a]

Year	Production[b] (10^6 Mg)	Sales in physical units[b] (10^6 Mg)	Ratio of sales in physical units to production	Dollar sales[b,c] ($\$10^6$)
1955	2.6	2.4	92	1,651
1956	2.9	2.6	90	1,730
1957	3.0	2.7	90	1,811
1958	3.1	2.8	90	1,819
1959	3.9	3.5	90	2,333
1960	4.1	3.6	88	2,351
1961	4.3	3.9	91	2,427
1962	5.0	4.5	90	2,658
1963	5.5	4.7	85	2,770
1964	6.1	5.3	87	2,930
1965	6.9	5.9	86	3,346
1966	7.9	6.8	86	3,658
1967	8.0	6.9	86	3,547
1968	9.4	8.2	87	3,880
1969	10.7	9.0	84	4,235
1970	10.7	9.5	89	4,298
1971	11.7	10.2	87	4,541
1972	14.0	12.3	88	5,353
1973	16.4	14.6	89	6,644
1974	13.9	16.3	117	9,416
1975	13.4	11.3	84	8,461
1976	15.9		81	10,148
1977	18.3	15.4	84	12,822
1978	20.2	16.9	84	14,224
1979	21.7	18.5	85	17,705
1980	19.5	16.7	86	18,291
1981	20.6	17.9	87	19,597

[a] These data reflect some double counting due to the intraindustry trade already noted.

[b] These figures are based on summation of two International Trade Commission categories: plastics and resin materials, and elastomers (synthetic rubber).

[c] Dollar sales are in current dollars.

TABLE 9-6. EXPORT AND IMPORT VALUES OF INDUSTRIAL ORGANIC CHEMICALS (SIC 286) EXCLUDING GUM AND WOOD CHEMICALS (SIC 2861) FOR SELECTED YEARS BETWEEN 1972 AND 1981[15]

Year	Exports[a] ($\$10^6$)	Imports[a] ($\$10^6$)
1972	1,073.1	448.6
1977	2,879.4	1,094.8
1978	3,812.9	1,484.2
1979	5,493.9	1,784.7
1980	6,292.1	2,008.7
1981	6,500.0[b]	2,050.0[b]

[a] Current dollars.

[b] Estimated. U.S. Department of Commerce, Bureau of Industrial Economics.

TABLE 9-7. EXPORT AND IMPORT VALUES OF PLASTICS MATERIALS AND SYNTHETICS (SIC 282) FOR SELECTED YEARS BETWEEN 1972 AND 1981[16]

Year	Exports[a] ($\$10^6$)	Imports[a] ($\$10^6$)
1972	766.9	273.2
1977	1,751.6	385.6
1978	1,973.5	509.6
1979	3,181.2	513.8
1980	3,973.5	521.2
1981	3,861.2[b]	597.8[b]

[a] Current dollars.

[b] Estimated. U.S. Department of Commerce, Bureau of Industrial Economics.

the value of both exports and imports has just kept pace with the value of industry shipment. International competition in Plastics Materials and Resins (SIC 2821), however, is expected to erode the favorable trade balances that sector currently maintains.[16]

9.1.3.2.2 VOL storage terminals. Chemicals are stored in terminals for short periods partly because of the need for transshipment: changes in the mode of transportation between origin and final destination. Chemicals often are moved in bulk shipments to a distribution center by barge or rail car. These large shipments are then partitioned into smaller lots for transport by truck to areas not served by barge or rail. The amount of transshipment undertaken depends upon locations (origin and destination), alternative transportation costs, product stability, and storage costs.

Terminals are operated on a proprietary basis and by independent companies. Proprietary terminals are owned and operated exclusively by chemical producers as part of their distribution systems. Independently operated facilities, often called merchant terminals, provide storage services on a contract basis. The merchant terminals lease capacity to chemical producers for storage near markets not served by appropriate proprietary terminals and at points where transshipment occurs. They also may be used by producers when extra storage capacity is required on a short-term basis.

Most terminal operations store other liquid and dry bulk commodities in addition to VOLs. Liquids like petroleum, fats, fertilizers, and dry goods of many types commonly are stored at terminals. Depending on the terminal's location, chemicals account for 5 to 25 percent of a facility's bulk liquid capacity and a slightly greater percentage of revenues from bulk liquid storage.[10] At any given time a small percentage of a terminal's capacity will hold VOLs. Conversion of a tank from another use to VOL storage is possible but requires purging of the tank, an expensive and time-consuming process undertaken only about once every 5 to 10 years. Therefore, most tanks are believed to be in dedicated service as far as VOL storage is concerned.

9.1.4 Market Structure

Conditions addressed in the market structure section of this profile include vertical integration, market concentration, geographic distribution of plants, and barriers to entry.

9.1.4.1 Vertical Integration. A firm that produces raw materials or fabricated inputs used in production of its primary output or that engages in further processing or distributing of its primary output is said to be vertically integrated. Vertical integration is apparent among firms that produce, consume, and store VOLs.

9.1.4.1.1 VOL producer and consumer firms. The relationship between a firm's production cost and output price is affected, among other things, by the extent to which the industry is vertically integrated. Within VOL production and consumption, vertical integration is extensive. Captive consumption of VOLs averaged about 52 percent of total output during the period 1955 to 1978, a ratio that varied only slightly from year to year (see Table 9-4).

Vertical integration of VOL production and consumption extends to storage services. In addition to proprietary storage at the production site, many large firms establish proprietary terminals that can serve the needs of nearby markets quickly. Because VOL producers and consumers manufacture a range of non-VOL products, proprietary terminals also provide storage for other chemical and petroleum products (e.g., fuels). When proprietary storage capacity is not available, merchant terminals are leased to store these chemicals.

9.1.4.1.2 Merchant terminals. Many merchant terminal companies are proprietorships or partnerships, some with only a single terminal, and many are vertically integrated into distribution or repackaging services. Petroleum distributors are the most typical type of merchants providing chemical storage. A few operators are large, international corporations with many terminals in the United States and abroad. Typically, these large firms are integrated vertically into distribution and other transportation services.

9.1.4.2 Market Concentration. Market concentration addresses the issue of whether individual market participants exercise economic power. Typically, market concentration measures the share of business held by leading firms in an industry. Concentration ratios based on the four largest producers in an industry are cited most frequently.

Hundreds of VOL chemicals exist, covering a wide variety of production characteristics, output levels, applications and, consequently, market conditions. Many VOL chemicals (e.g., formaldehyde and alcohols) are manufactured by a relatively large number of firms through various processes. The products have a wide range of end uses in which substitute materials often can be used. These markets therefore tend to be highly competitive. Other VOL chemicals (e.g., succinonitrile and isoamylene) are manufactured by a small number of producers (in some cases, only one) and have no close substitutes in their end uses. In these markets, producers may be able to influence market prices considerably, at least in the short run.

The precise degree of market concentration in VOL production and consumption is difficult to evaluate because it varies considerably among products. However, a general assessment of the industry-wide situation may be made based on capacity share data presented in Table 9-8. These data suggest that no one company or group of companies dominates the industry. In 1976, the top 4 companies owned only 18 percent of total VOL capacity and the top 20 firms owned 45.39 percent of total VOL capacity.

9.1.4.3 Geographic Distribution of Plants.

9.1.4.3.1 VOL producers. The location of VOL storage is crucial to its commercial value. Table 9-9 contains 1972 and 1977 data on geographic distribution of production sites of industrial organic chemicals.* VOLs are produced in almost every region of the country (see Table 9-9). Most of the plants are small, employing fewer than 20 workers. The largest plants are clustered in the South near raw material supplies and in the Middle Atlantic States close to industries that use the finished products.

The 1977 statistics suggest that three changes may have taken place in the VOL-producing and VOL-consuming industries. First, a shift in the location of plants is apparent among different regions of the country. These data indicate that the number of plants in the Middle Atlantic and West North Central States is declining and that a large portion of the new plants are being constructed in the East North Central and West South Central States. Second, plant size, as measured by the number of employees, appears to be increasing. In each of the three sectors comprising SIC 286, Industrial Organic Chemicals, the percentage of large plants increased. Third, a shift in resources away from SIC 2861, Gum and Wood Chemicals, to SIC 2869, Industrial Organic Chemicals Not Elsewhere Classified, is apparent. The former industry lost 20 plants and the latter gained 55 plants in 5 years.

9.1.4.3.2 VOL consumers. The geographic distribution of VOL consumers is presented in Table 9-10. In general, plants in this industry (SIC 282, Plastics Materials and Synthetics) are larger than VOL-producing plants are;

---

*Industry definitions for SIC 2861, SIC 2865, and SIC 2869 used by the Bureau of the Census do not correspond precisely to definitions of the organic chemicals industry used by the International Trade Commission. Thus, data presented in Table 9-9 are not strictly comparable with data presented in Table 9-4.

TABLE 9-8. INDUSTRY-WIDE MARKET CONCENTRATION BASED ON CAPACITY SHARE DATA, 1976[17]

Number of firms	Percent of firms	Estimated capacity (Mg)	Percent of industry capacity
Top 4	0.72	58,751.8	18.3
Top 8	1.43	91,820.6	28.6
Top 20	3.58	145,752.34	45.39
Top 40	7.17	186,681.62	58.14

TABLE 9-9. GEOGRAPHIC DISTRIBUTION OF ESTABLISHMENTS, EMPLOYEES, AND VALUE OF SHIPMENTS OF SIC 286, INDUSTRIAL ORGANIC CHEMICALS[18] [19][a]

SIC code	Year	Location[b]	Establishments Total	Establishments With 20 or more employees	Employees (10^3)	Value of shipments ($\$10^6$)	Year	Establishments Total	Establishments With 20 or more employees	Employees (10^3)	Value of shipments ($\$10^6$)
2861	1972	United States	139	41	5.9	332.3	1977	119	37	4.8	391.3
		Middle Atlantic	18	4	0.2	10.8					
		West North Central	33	7	0.8	27.3		25	6		
		South Atlantic	32	12	2.7	171.0		18	8		
		East South Central	16	9	1.6	86.9		1	1		
		West South Central	22	4	0.3	21.2		23	4	>0.2	>9.0
		Pacific	6	3	0.2	11.1		3	2		
2865	1972	United States	173	117	28.2	2,044.5	1977	191	127	35.7	5,637.0
		New England	11	7	1.2	60.5		10	4		
		Middle Atlantic	66	47	12.7	698.6		68	45	16.7	1,933.8
		East North Central	29	21	>2.5			33	23		
		West North Central	4	1	0.15-0.25						
		South Atlantic	24	18	4.8	368.5		27	21		
		East South Central	10	7	1.4	185.6		7	7		
		West South Central	18	13	2.2	324.4		16	13		
		Pacific	9	3	0.15-0.25			8	5		
		All other States									
2869	1972	United States	514	295	101.7	9,179.1	1977	569	346	112.3	24,232.8
		New England	33	15	5.8	212.3		29	18		
		Middle Atlantic	141	83	21.4	1,457.7		135	81	16.2	2,318.3
		East North Central	82	45	≥2.5			96	50		
		West North Central	21	6	1.0-2.49			20	6		
		South Atlantic	69	41	13.7	1,164.8		70	50		
		East South Central	30	18	8.2	666.5		32	24		
		West South Central	87	65	34.7	4,393.6		110	83	45.7	14,075.9
		Mountain	5	3	0.25-0.49			5	3		
		Pacific	46	19	≥2.5			42	19	3.6	552.2
		All other States									

---

[a] Blanks represent data withheld to avoid disclosing figures for individual companies.

[b] Geographic regions as defined by the Bureau of the Census are: NORTHEAST New England States: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont. Middle Atlantic States: New York, New Jersey, and Pennsylvania. NORTH CENTRAL East North Central States: Ohio, Indiana, Illinois, Michigan, and Wisconsin. West North Central States: Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas. SOUTH South Atlantic States: Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, and Florida. East South Central States: Kentucky, Tennessee, Alabama, and Mississippi. West South Central States: Arkansas, Louisiana, Oklahoma, and Texas. WEST Mountain States: Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, and Nevada. Pacific States: Washington, Oregon, California, Hawaii, and Alaska.

TABLE 9-10. GEOGRAPHIC DISTRIBUTION OF ESTABLISHMENTS, EMPLOYEES, AND VALUE OF SHIPMENTS OF SIC 282, PLASTICS MATERIALS AND SYNTHETICS[20] [21] [a]

SIC code	Year	Location[b]	Establishments Total	Establishments With 20 or more employees	Employees (10^3)	Value of shipments ($\$10^6$)	Year	Establishments Total	Establishments With 20 or more employees	Employees (10^3)	Value of shipments ($\$10^6$)
2821	1972	United States	323	263	54.8	4,478.2	1977	397	310	57.2	10,818.2
		New England	30	28	≥2.5			34	25		
		Middle Atlantic	66	53	≥2.5			81	65		
		East North Central	80	64	≥2.5			81	63		
		West North Central	12	11	1.0-2.49			11	8		
		South Atlantic	35	27	≥2.5			54	46		
		East South Central	18	15	4.5	333.4		23	19		
		West South Central	35	31	≥2.5			44	36		
		Pacific	46	35	1.0-2.49			59	43		
2822	1972	United States	59	34	11.8	1,089.4	1977	63	30	10.0	1,863.3
		East North Central	13	5	1.0-2.49			11	3		
		South Atlantic	7	6	0.5-.99						
		East South Central	3	3	1.0-2.49			3	3		
		West South Central	18	16	≥2.5			14	13		
		Pacific	8	2	0.25-0.49						
2823	1972	United States	20	14	19.0	627.9	1977	10	10	15.9	998.9
		Middle Atlantic	6	4	>2.5			1	1		
		East North Central	1	1	1.0-2.49						
		South Atlantic	8	1	1.0-2.49			5	5		
		East South Central	3	2	1.0-2.49			2	2		
2824	1972	United States	60	54	76.3	3,601.4	1977	66	58	74.0	6,379.7
		New England						3	3		
		Middle Atlantic	6	4	0.25-4.9			2	1		
		South Atlantic	35	35	54.6	2,636.2		43	41		
		East South Central	15	14	21.3	950.6		12	12		
		East North Central						1	1		

[a] Blanks represent data withheld to avoid disclosing figures for individual companies.
[b] Geographic divisions as defined by the Bureau of Census are listed in Table 9-9.

over 75 percent of SIC 282 firms employ more than 20 workers. Overall, the industry is not as geographically concentrated as the industrial organic chemical industry is; but a high proportion of the plants are located in the Middle Atlantic, South Atlantic, and East North Central States.

9.1.4.3.3 Terminals. Data on capacity of merchant storage terminals, by State, are presented in Table 9-11. Approximately half (51 percent) of ILTA members are located in Texas, Louisiana, and New Jersey. These data must be interpreted cautiously with respect to VOL storage, however, because capacity estimates include many large petroleum storage tanks.

Although data on proprietary storage are not available, major oil firms that also produce VOLs often use their petroleum distribution terminals to handle chemicals. Many of these terminals, along with a number of terminals owned by chemical producers, are located along the inland waterway system that covers the North Central and Southern States.

9.1.4.4 Barriers to Entry. Although entry into and departure from the principal industries storing VOL could not be measured directly, some general comments are appropriate about conditions facing firms considering entry into the industry. A chemical producer or consumer can enter by acquiring tanks for proprietary storage or vertical integration. These firms face apparently surmountable barriers of capital formation, expertise, and local laws and standards. A storage facility requires expenditures for tanks, land, and concrete pads. Support services, labor, and maintenance must be provided. Such firms also must find or develop expertise in managing storage operations. Before construction of the facility can begin, permits must be obtained from Federal, State, and local Government agencies, and construction usually must conform to standards set by private organizations. All of these barriers can be overcome if the internal rate of return on the investment is sufficiently attractive. If a firm can raise the capital for a relatively expensive manufacturing facility, it almost certainly can raise the capital for an associated storage facility.

Potential merchant terminal operators face similar barriers. Capital formation, in particular, is often more difficult for a small business than for a larger business or for new terminal operators than for existing operators wishing to expand their operations. Even so, the cost of a terminal is simply not large enough to prevent entry into the industry.

TABLE 9-11. TOTAL 1982 MERCHANT LIQUID BULK CAPACITY, BY STATE[8]

State	Total capacity (m^3)	Share of total U.S. capacity (%)
Alabama	337,269	1.22
Arizona	24,009	0.09
Arkansas	72,989	0.26
California	1,428,962	5.17
Colorado	12,100	0.04
Connecticut	550,459	1.99
Delaware	184,758	0.67
Florida	294,198	1.06
Georgia	663,982	2.40
Illinois	1,866,126	6.76
Indiana	135,180	0.49
Iowa	781,948	2.83
Kansas	291,471	1.06
Kentucky	4,055	0.01
Louisiana	4,001,388	14.51
Maryland	260,190	0.94
Michigan	39,988	0.14
Minnesota	581,719	2.11
Mississippi	154,548	0.56
Missouri	239,763	0.87
Nebraska	273,035	0.99
Nevada	8,268	0.03
New Jersey	4,230,975	15.32
New York	1,464,066	5.30
North Carolina	409,807	1.48
North Dakota	126,271	0.46
Ohio	257,501	0.93
Oklahoma	440,876	1.60
Oregon	429,917	1.56
Pennsylvania	1,416,862	5.13
South Dakota	156,186	0.57
Tennessee	133,823	0.48
Texas	5,944,659	21.53
Virginia	20,218	0.07
Washington	187,886	0.68
West Virginia	120,840	0.44
Wisconsin	64,939	0.24
Total	27,617,231	100.00

9.1.5 Market Conduct

This section focuses on pricing behavior in the industrial organic chemicals and merchant terminals industries. Observations may facilitate assessment of price impacts of the proposed new source performance standard (NSPS).

9.1.5.1 Chemical Pricing. VOL producers and consumers manufacture many chemicals embracing a wide variety of characteristics. Potential for substitution and/or intermediate competition varies considerably from chemical to chemical. In general, though, the incentive to substitute away from a specific VOL when its price increases is diminished by the fact that good substitutes are frequently also VOLs. The substitutes are therefore also subject to cost and price changes related to a storage standard or other common factors.

Table 9-12 presents price data for industrial organic chemicals and plastics, resin materials, and elastomers from 1955 to 1981. These data indicate that during the era of stable, low-energy prices from 1955 to 1973, chemical prices remained stable in current terms and declined slightly in constant terms. Following the rapid increase in energy prices in the fall of 1973 and in 1974, the average current price of organic chemicals rose sharply and continued to increase between 1975 and 1981. However, constant prices increased at a much slower rate than did current prices.

Data in Table 9-12 also indicate that both current and constant prices for plastics and resins declined during the period 1955 to 1972 as energy prices remained stable and production technology improved. However, the sharp increase in raw material prices in 1973 resulted in a 29-percent increase in current prices for those products between 1973 and 1974. The industry's product prices again increased substantially between 1974 and 1975. Thereafter, the rate at which current prices increased slowed, and real prices remained stable between 1975 and 1977. Between 1977 and 1981, the real price of plastics, resin materials, and elastomers fell.

9.1.5.2 Merchant Terminal Storage Pricing. Results of a telephone survey of nine merchant terminal operators suggest two general pricing schemes are practiced. Under the simpler method, the terminal charges a fee (often called a throughput fee) for each unit of chemical that passes through its storage tanks.* Individual terminals adjust throughput fees to reflect varia-

---

*For example, a customer may require storage for 1.5 million ℓ/yr of methyl alcohol. If the throughput rate for methyl alcohol is 3¢/ℓ, the total annual cost to the customer of storing this volume is $45,000.

TABLE 9-12. HISTORICAL PRICE DATA FOR INDUSTRIAL ORGANIC CHEMICALS AND PLASTICS, RESIN MATERIALS, AND ELASTOMERS, 1955 to 1981

	Industrial organic chemicals		Plastics, resins, and elastomers		
	Average unit prices		Average unit price		
Year	Current[a] (¢/kg)	Constant[b] (¢/kg)	Current[a] (¢/kg)	Constant[b] (¢/kg)	Producer price index for all manufactures[c]
1955	24	27	69	79	86.6
1956	24	27	67	74	90.0
1957	24	26	67	72	92.8
1958	26	27	65	69	93.8
1959	28	30	67	70	94.6
1960	28	30	65	69	94.7
1961	30	32	62	66	94.4
1962	29	30	59	63	94.5
1963	28	30	59	62	94.3
1964	27	28	55	58	94.8
1965	27	28	57	59	96.3
1966	28	28	54	54	99.0
1967	29	29	51	51	100.0
1968	29	28	47	46	102.6
1969	27	25	47	44	106.2
1970	26	24	45	41	110.2
1971	27	23	45	39	113.8
1972	26	22	44	37	117.9
1973	28	21	45	35	129.2
1974	44	28	58	37	154.1
1975	53	31	75	44	171.1
1976	59	33	79	44	179.0
1977	62	32	83	44	190.1
1978	65	32	84	41	204.2
1979	72	31	96	42	228.8
1980	83	32	110	42	261.5
1981	92	32	109	38	286.0

---

[a] Average unit price was calculated from Tables 9-4 and 9-5 as total sales value divided by total sales quantity. Rounding may make converted values appear inconsistent.

[b] Constant prices, measured by 1967 dollars, were calculated by dividing the average constant unit price of the chemicals by the producer price index for all manufactured goods.

[c] References 11, 22.

tions in quality of storage service provided to the customer and in physical properties of the chemical to be stored.

Under the more complex pricing system, the terminal charges a basic fixed fee for the duration of the storage contract to recover fixed costs associated with the terminal's storage facilities and costs associated with handling a minimum volume of throughput.* If throughput exceeds the level on which the minimum charge is based, the terminal levies an additional per-unit charge on the additional volume of chemicals it handles to cover the cost of additional labor, energy, and materials inputs. Often, as the volume of throughput and the number of tank turnovers (throughput divided by tank capacity) increase, the price charged by the terminal for additional throughput is reduced, reflecting economies of scale in handling large numbers of turnovers.† Companies apparently vary the fixed fee they charge according to market conditions so discounts may be offered when demand for storage services is low. Payment for additional throughput services is made in two parts. Half of the throughput rate is collected as the chemicals are unloaded from trucks, rail cars, or barges into the storage tank and the remainder is collected as the chemicals leave storage. The basic fee is collected while the tank is used.

Other storage pricing systems may be used in addition to the two methods described here but were not identified in the survey, which covered only approximately 10 percent of all merchant terminal operators. Details of the pricing policies used by the remaining 90 percent of VOL merchant terminals were not available.

---

*Usually the minimum throughput represents four complete turnovers of the rented storage tanks' volume. If a 1-million-ℓ tank is rented by a customer, the customer will be able to store up to 4 million ℓ in the tank in any given year before incurring additional charges.

†An example of the second pricing scheme is as follows. The annual rental fee for storing methyl alcohol in a 250,000-ℓ tank might be $30,000. If annual throughput exceeds 1 million ℓ (i.e., the chemicals in the tank are turned over more than four times), a surcharge of 2¢/ℓ of chemicals might be levied for the next 500,000 ℓ of throughput. The surcharge might be lowered to 1.5¢/ℓ for all annual throughput exceeding 1.5 million ℓ. Thus, if total annual throughput is 1.5 million ℓ, total terminal revenues might be $40,000. If throughput rises to 2 million ℓ, terminal revenues might increase to $47,000.

Finally, it should be noted that virtually every storage contract is unique because of the large number of services offered by terminals to customers. Variables that affect basic rates and throughput surcharges include options that may be added to a tank (e.g., floating roofs, nitrogen blankets, refrigeration, insulation, steam heating, special linings, auxiliary pumps, vapor recovery systems, and other pollution control devices), modes of transportation, length of contracts,* age of tanks,† and corrosivity and toxicity of chemicals.‡ Additional services add to storage costs, which are passed directly to the customer in the contract.

9.1.6 Market Performance

9.1.6.1 VOL Producers' and Consumers' Financial Characteristics. Two recent EPA reports presented data and results of an analysis on fiscal year (FY) 1977 financial data for a sample of 100 chemical firms.[23] [24] It was estimated that the average after-tax cost of capital measured in current dollar terms for chemical firms was 10.81 percent. If capital costs are distributed normally, 95 percent of the industry firms face after-tax capital costs ranging from 8.95 to 12.67 percent.

9.1.6.2 Merchant Terminals' Financial Characteristics. A financial profile of terminal services could not be developed because (1) financial data are not provided by many firms and (2) data on the terminal operations of vertically integrated firms are not reported separately from other operations on Security and Exchange Commission (SEC) 10K forms.

9.1.7 Projected New and Reconstructed VOL Storage Tanks: Calendar Years 1984-1988

The projection of new and reconstructed tanks has two components: tanks that replace retiring tanks and tanks that increase total storage capacity. The projection's methodology and results for each component are discussed separately below.

---

*The basic rate of a 1-year contract is likely to be higher than that of a 15-year contract due to the capital recovery factory.

†In Texas, State regulations require different designs on tanks built before and after 1976.

‡Corrosivity requires relining of the tanks, and toxicity requires special handling equipment and techniques.

Replacement tanks were projected by three steps. First, the Federal Reserve Board index of organic chemical production has been used as a proxy of VOL chemical production capacity during the 1954 to 1977 period to estimate the number of tanks in place in each year from 1954 to 1977.[25] [26] This index has been smoothed through regression procedures,* and the total number of VOL tanks in place for each of the years is computed based on the regression equation and 1977 data on the number of VOL storage tanks.[27] [28] Inherent in this procedure is the assumption that the ratio of storage capacity to production capacity is constant.

Second, a tank age profile for 1977 has been constructed through a recursive procedure that assigns ages to tanks based upon the number of tanks existing in prior years as established in the first step of this methodology. Additional assumptions required for this procedure are as follows:

1. A tank's economic life is assumed to be 20 years, an assumption consistent with the tank cost methodology of Chapter 8.
2. During the initial year (1954) of the recursive process the age of tanks was uniformly distributed between 1 and 20 years. This assumption is fairly arbitrary but, because the number of tanks in 1954 (3,800) is estimated to be less than 14 percent of the total number in 1977 (27,540), alternative assumptions are unlikely to produce substantially different results.
3. All obsolete (20-year-old) tanks were replaced and new tanks purchased at the beginning of each year. This assumption is necessary simply because the recursive procedure is a discrete approximation of a continuous process. Alternative assumptions, including refinements in the time interval used, also are unlikely to produce substantially different results.

The following recursive procedure is employed: given the age distribution of tanks in 1954 (assumption 2 above), age all existing tanks 1 year; compute the number of replacement tanks required in 1955 (the number of tanks that have aged to 21); compute the number of new, nonreplacement tanks required in 1955 (the difference between total tanks in 1955 and 1954); and construct an age distribution of tanks in 1955. This process is repeated year by year until an age distribution of tanks for 1977 has been generated.

---

*The smoothed data are the predicted values of the index with a log linear specification: $\ln Y_t = 0.079\ t$; $\ln Y_t$ is the natural logarithm of the production index for year t (t = 1954 to 1977), and 0.079 is estimated through least squares procedures with the regression line constrained to pass through the observation for 1977.

The third step in projections of tank replacement for 1984 to 1988 is to use the 20-year economic life assumption and the age distribution of tanks in 1977 to compute the number of tanks in each of the projection years. That is, each tank in the 1977 age profile that will be 21 years old in a projection year will be replaced in that year. These results indicate that 5,890 replacement tanks will be constructed during the period 1984 to 1988 (see row 1 of Table 9-13).

Projected VOL storage tank construction that adds new capacity nationwide is based upon forecasted growth of the organic chemicals industry. The Federal Reserve Board index of organic chemical production, extrapolated to the 1984 to 1988 period from data for the period 1954 to 1977, indicates an average annual growth rate of about 7.9 percent. Chemical industry observers from the American Chemical Society and the U.S. Department of Commerce have independently observed some apparent slackening in long-term growth in the organic chemicals sector. They estimate a probably more realistic growth rate of 4 to 6 percent for the projection period.[29] [30] On this basis, 5 percent annual growth in the organic chemicals industry and proportionate increases in total tank and production capacities are assumed to project new, nonreplacement capacity tanks (see row 2 of Table 9-13). Over the period 1984 to 1988, 10,200 new tanks are projected. By comparison, a 7.9-percent growth rate from 1977 would have resulted in 21,620 projected new-capacity tanks in the period. Total tank construction in the projection period is shown in row 3 of Table 9-13.

Finally, projected tank construction between 1984 and 1988 is disaggregated by capacity and vapor pressure. A 1977 survey of VOL storage tanks provided an estimated pressure and volume distribution for the tanks (see Table 9-14 for a summary).[31] [32] This percentage distribution table was then multiplied by the projected new tank totals of Table 9-13 to yield volume and pressure intervals for the period 1984 to 1988.* Table 9-15 shows the summary

---

*The original percentage distribution table includes 24 volume intervals and 18 vapor pressure intervals.

TABLE 9-13. PROJECTION OF VOL STORAGE TANK CONSTRUCTION--1984 TO 1988 ALL CAPACITIES, VAPOR PRESSURES, AND ROOF DESIGNS

Tanks	1984	1985	1986	1987	1988	Total (1984-1988)
Total number of new tanks built nationwide to replace retiring, existing tanks	1,030	1,100	1,170	1,250	1,340	5,890
Total number of new tanks built nationwide to supplement existing VOL storage capacity at an annual growth rate of 5 percent	1,850	1,940	2,030	2,140	2,240	10,200
Total number of new tanks built nationwide--replacement plus 5 percent new capacity growth	2,880	3,040	3,200	3,390	3,580	16,090

TABLE 9-14. ESTIMATED PERCENTAGE DISTRIBUTION OF VOL STORAGE TANKS BY VAPOR PRESSURE AND TANK CAPACITY, 1977[a]

Capacity (m^3)	Vapor pressure (kPa) 0-3.5	3.5-6.9	6.9-10.3	10.3-34.5	34.5-58.6	≥58.6	TOTAL
0-75	27.98	6.55	3.22	5.14	1.23	0.39	44.51
75-150	9.26	1.58	0.93	2.32	0.03	0.13	14.25
150-375	8.94	1.68	1.17	2.28	0.19	0.06	14.32
375-3,750	12.84	2.98	1.58	5.59	0.46	0.16	23.61
3,750-15,000	1.12	0.36	0.35	1.10	0.09	0.00	3.02
≥15,000	0.03	0.00	0.07	0.19	0.00	0.00	0.29
TOTAL	60.17	13.15	7.32	16.62	2.00	0.75	100.00

[a] The original percentage distribution table covers 24 volume intervals and 18 pressure intervals. This table summarizes the distribution table for relevant, aggregate intervals of both volume and pressure. All computations of economic impact were performed based on the intervals and data of the original distribution table.

TABLE 9-15. PROJECTION OF VOL STORAGE TANK CONSTRUCTION BY VAPOR PRESSURE AND TANK SIZE, 1984 to 1988[a,b]

Capacity (m^3)	Vapor pressure (kPa) 0-3.5	3.5-6.9	6.9-10.3	10.3-34.5	34.5-58.6	≥58.6	TOTAL
0-75	4,500	1,050	520	830	200	60	7,160
75-150	1,490	250	150	370	10	20	2,290
150-375	1,440	270	190	370	30	10	2,300
375-3,750	2,070	480	250	900	70	30	3,890
3,750-15,000	180	60	60	180	20	0	490
≥15,000	10	0	10	30	0	0	50
TOTAL	9,680	2,120	1,180	2,670	320	120	16,090

[a] The original percentage distribution table covers 24 volume intervals and 18 pressure intervals. This table summarizes the distribution table for relevant, aggregate intervals of both volume and pressure. All economic impact computations were performed based on the intervals and data from the original distribution table.

[b] Rows and columns may not sum to totals due to rounding.

result of this multiplication for all new tanks projected for 1984 to 1988. This application of estimated 1977 tank distribution assumes VOL storage tank distribution by vapor pressure and tank size will remain constant over time.

All projections described in this subsection are based on assumptions and data described above. While projections are as accurate as the data and assumptions permit, changes in the economy, technological advances, development of competitive substitutes, discovery of new product uses, and changes in market stability may affect actual industry growth. Such occurrences are difficult to anticipate. These projections reflect the most probable scenario and are the best possible, given the data available.

9.2 ECONOMIC IMPACTS OF REGULATORY ALTERNATIVES

This section presents the regulatory alternatives' estimated impacts on users of VOL storage tanks. Six regulatory alternatives are considered, the first of which is the baseline case (Regulatory Alternative 0) from which impacts are measured. In general, the alternatives become increasingly stringent from the baseline to Regulatory Alternative V. The economic impacts considered in turn are: impact on the product price based on two model plants, impact on investment for two model plants, impact on investment in VOL storage nationwide, and impact on annual costs of VOL storage nationwide.

9.2.1 Background

Estimated impacts of regulatory alternatives on product prices have been developed based on two model plants: an independent storage terminal, and a VOL chemical producer/consumer. Tank requirements and other characteristics of these two facilities are described in detail in Chapter 6. These facilities were selected for analysis because it is believed that they would experience relatively greater than average cost impacts as a result of imposition of any of the regulatory alternatives. The general approach and assumptions are discussed briefly before presentation of estimates.

In the long-run, the market price of a product produced by a competitive industry equals the average production cost for new facilities. Average production cost includes a normal return on investment (ROI) because firms will not choose to build a new facility unless they anticipate that market price will be sufficient to cover all costs. Thus, the change in average production cost of a new facility due to an NSPS is the best estimate of the long-run product price impact of the regulatory alternatives considered. Model facilities used here are expected to experience greater than typical average production cost increases because a relatively large proportion of their tanks would be affected by the regulation. Using the change in the production cost for these facilities to estimate price effects at an average facility, therefore, tends to overstate the regulatory alternatives' price effects.

As documented in Chapter 8, all regulatory alternatives except the baseline will increase tank fabrication costs. This cost increase can be considered the increase in price of tanks to the VOL tank users based on the same logic as outlined above. For a constant cost tank industry, as illustrated in Figure 9-2, this average cost increase will appear as a vertical shift in a horizontal supply curve from S to S'. The price of tank type i in year t will rise from P to P'.

However, long-run impacts of the regulatory alternatives on price of VOL storage services cannot be calculated from this price change alone because the regulatory alternatives considered here impact services and performance as well as price of tanks of a given volume and pressure. In principle, at least, these regulatory alternatives can affect cost of storage services in at least two other ways: they increase the storage cost because they reduce effective tank capacity due to insertion of an internal roof and decrease storage cost because they increase storage efficiency by reducing VOL vaporization and, hence, VOL losses.

An internal floating roof occupies about 0.5 m of vertical space in a storage tank, thus decreasing effective tank capacity. Capacity reduction is related to tank height and ranges from 6 to 12 percent of volume for a 75-m^3 tank 5 m high and between 2 and 4 percent of volume for a 20,000 m^3 tank 15 m high. Thus, other factors remaining constant, this feature would tend to increase the number of tanks impacted as more tanks are needed to store a given volume of VOL.

Reduction in VOL vaporization associated with the regulatory alternatives will decrease cost of storage services in two respects. First, the number of storage tanks required to meet given production and marketing requirements for VOL will decline because VOL previously stored and then lost due to evaporation is now saved for sale or use. Thus, storage capacity requirements are reduced to the extent that vapor losses in storage do not have to be considered when tank capacity needed for a given demand is calculated. The magnitude of reduction will depend on the effectiveness of vapor emission reduction and the

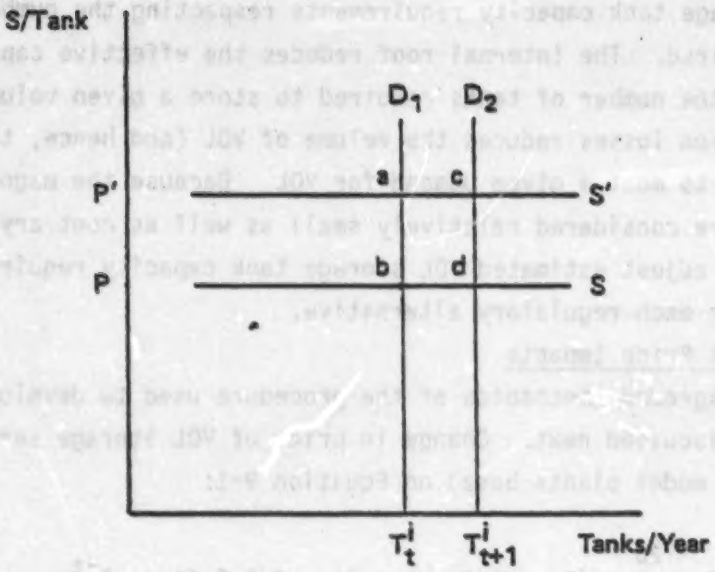


Figure 9-2. VOL storage tank market for tanks in volume interval i as characterized in the economic impact analysis.

relationship between storage tank capacity and VOL use. Assuming a turnover of 2.5 times a year and the equipment effectiveness described in Chapter 7, required tank storage capacity would be reduced by roughly 1 percent.

The second way in which increased tank efficiency will reduce cost of storage services is reflected in the value of VOL no longer lost to the atmosphere. This improvement in tank quality will offset at least partially any price increase of tanks. This consideration, as manifested in emission reduction credits, is incorporated into the economic analysis.

The proposed regulatory alternatives therefore exert two opposing influences on storage tank capacity requirements respecting the number of VOL storage tanks required. The internal roof reduces the effective capacity of tanks, increasing the number of tanks required to store a given volume, and the reduction in emission losses reduces the volume of VOL (and hence, the number of tanks) required to meet a given demand for VOL. Because the magnitudes of these influences are considered relatively small as well as contrary, no attempt is made to adjust estimated VOL storage tank capacity requirements to account for them in each regulatory alternative.

9.2.2 Product Price Impacts

With this background, mechanics of the procedure used to develop the price impacts is discussed next. Change in price of VOL storage services was estimated for both model plants based on Equation 9-1:

$$k_0 + k_1 = \mathrm{ITC} + \sum_{t=1}^{20} [(1 - G)(P \cdot Q - C) + G \cdot D_t] (1 + r)^{-t} , \qquad (9\text{-}1)$$

where

k_0 = initial incremental investment.

k_1 = incremental investment in year 10 discounted to the present.

ITC = investment tax credit (10 percent).

r = real after-tax discount rate (10 percent).

t = year (1,2,3,. . ., 20).

Q = annual output.

P = change in price.

C = incremental annual operating cost.

G = tax rate (49 percent).

D_t = straight line depreciation in year t, with an assumed 20-year commercial life for floating roofs and 10-year commercial life for seals.

Equation 9-1 is a financial balance equation stating that the present value of the investment and operating costs required by the regulatory alternative must equal the present value of the stream of revenues. Solving the equation for P obtains the price change of the product or service required if the plant or terminal operator is to achieve an ROI for the mandated equipment competitive with other investment opportunities.

General features of the financial balance computation are as follows. The firm obtains a 10-percent investment tax credit on the equipment purchase. Computation is made on an after-tax basis whereby the income tax rate is 49 percent of net revenues. All revenues are in constant 1982 dollars, so the 10-percent discount rate selected for this analysis is a constant (or real) after-tax rate. A 10-percent discount rate is consistent with that employed in Chapter 8 to annualize capital costs. As discussed in Subsection 9.1, financial data for 1977 from a sample of 100 chemical companies shows an average 10.81 percent after-tax rate of return. Given the 1977 inflationary economic environment, the real rate of return to the firms would likely have been somewhat less that 10 percent. Using a real after-tax discount rate that is arguably high tends to overstate the price impact of the regulatory alternatives. Finally, a 20-year commercial life for tanks was assumed in keeping with the analysis of Chapter 8.

Parameters assumed in the use of Equation 9-1 include a model terminal throughput rate of 39×10^6 kg/yr and a model VOL producer/consumer output of 80 percent of production capacity of 4.5×10^6 kg/yr. Capital costs and operating expenses are taken from Chapter 8. Equation 9-1 was solved both with and without adjustments, allowing a \$460/Mg credit for emission reductions to be subtracted from operating costs for each model plant. The \$460/Mg figure is based upon a weighted average price of organic chemicals computed for 1978 production and prices as inflated to 1982 dollars by a chemical producers price index.*

Projected price impacts on VOL storage services of the regulatory alternatives with and without credit for emission reductions are shown in Table 9-16. As anticipated, price impacts increase as the regulatory alternatives become more stringent. Recognition of the value of emission reduction credits reduces price impacts.

These values were put in perspective through the following: price impacts were divided by estimated product price and multiplied by 100 to obtain estimated percentage change in product prices for the two model plants; \$460/Mg was used to estimate product price of the model producer/consumer and \$0.01/kg was used as average storage charge of the model independent terminal. This latter value is based upon the model terminal's estimated capital cost, inclusive of land and tank foundations, of \$1.72 × 10^6 (in 1982 dollars) and operating costs equal to 7 percent of capital costs. These costs were applied to Equation 9-1 and solved for price to determine the 1¢/kg figure. This capital cost, however, does not include purchase and installation costs of pumps, piping, gauges, etc., that ordinarily constitute a substantial portion of a storage terminal's capital expenses. Thus, the capital cost estimate is conservative in that if higher capital costs were used, the computed storage price would be higher, and the percentage change in price due to the regulatory alternatives would be even lower.

Table 9-17 presents the estimated percentage price changes for VOL producers/consumers and VOL terminals for each regulatory alternative. For the VOL producer/consumer, the base used to calculate price change was the estimated VOL price. Because VOL storage constitutes a relatively small share of VOL costs, percentage changes are very low indeed: less than 0.5 percent for all but Regulatory Alternative V. For the model terminal, the base used to calculate price change was the estimated storage price. Because storage tanks are a significant component of storage costs, the percentage change in average storage price at the model terminal is somewhat higher, ranging from 3.7 to 4.3 percent for Regulatory Alternatives I through IV and 11.8 percent

---

*The 1978 weighted average price was obtained from Reference 24. Inflation to 1982 was performed based on the Industrial Chemical Producers Price Index from the Chemical Engineering Journal. Adjustment is documented in Reference 33.

TABLE 9-16. PRICE IMPACTS OF THE REGULATORY ALTERNATIVES FOR THE MODEL TERMINAL AND MODEL PRODUCER/CONSUMER

	Model independent terminal (¢/kg)		Model producer/consumer (¢/kg)	
Regulatory alternative	Without credit for emission reductions	With credit for emission reductions[a]	Without credit for emission reductions	With credit for emission reductions[a]
I	0.049	0.037	0.15	0.11
II	0.050	0.038	0.17	0.11
III	0.051	0.038	0.20	0.11
IV	0.056	0.043	0.23	0.14
V	0.132	0.118	0.72	0.63

[a] Credit for emission reductions is calculated in Chapter 8 based on a VOL price of $460/Mg (in 1982 dollars).

TABLE 9-17. PERCENTAGE CHANGE IN OUTPUT PRICE FOR THE MODEL PLANTS DUE TO THE REGULATORY ALTERNATIVES

	Model independent terminal[a]		Model producer/consumer[b]	
Regulatory alternative	Without credit for emission reductions	With credit for emission reductions[c]	Without credit for emission reductions	With credit for emission reductions[c]
I	4.9	3.7	0.3	0.2
II	5.0	3.8	0.4	0.2
III	5.1	3.8	0.4	0.2
IV	5.6	4.3	0.5	0.3
V	13.2	11.8	1.6	1.4

[a] Average price of storage per kilogram was assumed to be $0.01 (in 1982 dollars).

[b] Average price of VOL was assumed to be $460/Mg (in 1982 dollars).

[c] Credit for emission reductions is calculated in Chapter 8 based on a VOL price of $460/Mg (in 1982 dollars).

for Regulatory Alternative V with a credit for emission reductions. The large difference in percentage change in price for the two types of facilities is, therefore, due more to difference in price base used for calculations than to differences in tank composition.

9.2.3 Investment Impacts

Investment impacts of the regulatory alternatives for the model plant and VOL storage industry are provided below.

9.2.3.1 Model Plant Investment Impacts. As reported in Chapter 8, installed capital cost of VOL storage tanks alone for the model terminal is an estimated $1.07 million in 1982 dollars, and installed capital cost of storage tanks alone for the model chemical producer/consumer is an estimated $0.25 million in 1982 dollars. Additional capital costs associated with each regulatory alternative are computed for each model plant. These costs, previously presented in Chapter 8, are consolidated in Table 9-18. They show additional investment requirements above the baseline for each of the regulatory alternatives. For the model independent terminal, the additional investment required ranges from $56,000 for Regulatory Alternative I to almost $185,000 for Regulatory Alternative V. The additional investment required of the model producer/consumer is considerably lower because fewer tanks are involved. The additional investment required of the model producer/consumer under Regulatory Alternative I is just under $16,000, barely over a quarter of the investment required of the model independent terminal under the same regulation. Under Regulatory Alternative V, the model producer/consumer would be required to invest $91,000 more for tanks than for the baseline. This amount is approximately half that required of the model independent terminal under that alternative.

9.2.3.2 Nationwide Investment Impacts. Nationwide impacts depend on volume and vapor pressure characteristics of new tanks in each year of analysis. Therefore, the first step in estimating the nationwide investment impact of regulatory alternatives is to estimate the number of new tanks that would be subject to VOL regulations by year, t; by volume interval, i; and by pressure interval, p. As described in Subsection 9.1.7, estimation is by scalar multiplication of a percentage distribution of tanks table by each annual projection of new tanks. The tank distribution table contains estimates of percentage of tanks in each volume and pressure interval based upon the 1977 survey of VOL storage tanks.[27] [28] The resulting values, T_t^{ip}, are the

TABLE 9-18. ADDITIONAL INVESTMENT REQUIRED BY EACH OF THE REGULATORY ALTERNATIVES FOR THE MODEL INDEPENDENT TERMINAL AND MODEL PRODUCER/CONSUMER
(10^3 1982 dollars)[a]

Regulatory alternatives	Model independent terminal	Model producer/ consumer
I	56.0	15.8
II	56.6	16.0
III	56.6	16.0
IV	71.8	23.2
V	184.8	90.8

[a] For comparison, the baseline cost of tanks would be $1.07 million for the model terminal and $250,000 for the model producer/consumer.

number of VOL tanks in year t, volume interval i, and pressure interval p projected to be subject to regulation.

In conjunction with the baseline conditions of Chapter 3, these values are then used to estimate impacted tank population under each regulatory alternative. Impacted tank population is that portion of the new tank population in any year that actually will undergo design changes and experience cost increases under each regulatory alternative. The impacted tank population for any regulatory alternative, year, and volume interval is found when T_t^{ip} values are summed over appropriate pressure intervals and scaled by appropriate baseline assumptions. For example, summation over vapor pressures for the volume interval 95 m^3 to 115 m^3 under Regulatory Alternative I excludes VOL tanks containing liquids whose vapor pressures are less than 3.5 kPa because they are lower than the 3.5-kPa baseline cutoff. In addition, this summation scales the number of remaining tanks in the volume interval by 0.65 because the baseline assumes that 35 percent of the new VOL storage tanks in that interval would be built with internal floating roofs even without Regulatory Alternative I due to State Implementation Plans (SIPs) already in effect. The resulting value, T_t^i, is the estimated number of tanks in volume interval i and year t impacted by Regulatory Alternative I.

Table 9-19 shows the tank population impacted by Regulatory Alternative I as a percentage of projected new VOL storage tank population. Actual number of tanks impacted will vary by year. Table 9-20 presents similar data for Regulatory Alternatives II through V. Percentages are the same for each of these four regulatory alternatives because they cover the same volume and pressure ranges and because the baseline conditions assume none of these technologies would have been adopted otherwise.

Calculation of T_t^i is therefore based on the number of new storage tanks projected in Subsection 9.1.7. Projections were developed in the absence of an NSPS for storage tanks. With higher prices for a product, due for example to an NSPS, the quantity of a commodity consumed typically decreases. The decision to treat the quantity of tanks purchased in any year as fixed regardless of a tank's estimated price increase due to each of the regulatory alternatives is based upon the following analysis.

TABLE 9-19. THE NEW TANK POPULATION IMPACTED BY REGULATORY ALTERNATIVE I AS A PERCENTAGE OF THE PROJECTED NEW TANK POPULATION

Tank volume (m^3)[a]	Percentage of new tank population Tanks with vapor pressure between 3.5 and 10.3 kPa		Percentage of new tank population Tanks with vapor pressure greater than 10.3 kPa
75[b] to 95	--	2.73[c]	--
95 to 150	--	1.47[c]	--
150 to 375	1.85		0
375 to 3,750	2.95		0
3,750 to 15,000	0.46		0
>15,000	0.05		0

[a] The six volume intervals presented here are aggregates. Calculations are performed based on the corresponding percentages from the 24 volume intervals of the 1977 survey.[27] [28]

[b] Tanks with volume less that 75 m^3 are below the minimum cutoff point considered for Regulatory Alternative I.

[c] Percentages of projected new tank population for tanks with volume capacities between 75 and 95 m^3 and between 95 and 150 m^3 are for all tanks having vapor pressure greater than 3.5 kPa.

TABLE 9-20. THE NEW TANK POPULATION IMPACTED BY REGULATORY ALTERNATIVES II THOUGH V AS A PERCENTAGE OF THE PROJECTED NEW TANK POPULATION

Tank volume (m^3)[a]	Percentage of new tank population Tanks with vapor pressures between 3.5 and 10.3 kPa		Tanks with vapor pressures greater than 10.3 kPa
75[b] to 95	--	2.73[c]	--
95 to 150	--	2.26[c]	--
150 to 375	2.85		2.53[d]
375 to 3,750	4.56		6.22[d]
3,750 to 15,000	0.71		1.19[d]
>15,000	0.07		0.19[d]

[a] The six volume intervals presented here are aggregates. Calculations are performed based on corresponding percentages from the 24 volume intervals of the 1977 survey.[27,28]

[b] Tanks with volume less that 75 m^3 are below the minimum cutoff point considered for Regulatory Alternatives II through V.

[c] Percentages of projected new tank population for tanks with volume capacities between 75 and 95 m^3 and between 95 and 150 m^3 are for all tanks having vapor pressure greater than 3.5 kPa.

[d] Baseline control assumptions specify that tanks with volume greater than 150 m^3 and vapor pressures greater than 76 kPa have vapor control systems or are pressure vessels. Because the upper vapor pressure interval of the 1977 sample intervals covered all tanks with vapor pressures greater than 59 kPa, there was no basis in the sample data to distinguish between tanks in that interval with vapor pressures greater than 76 kPa and those with vapor pressure less than 76 kPa. A working assumption that all the tanks in the upper interval had pressures between 59 and 76 kPa was adopted. Only a small number of tanks were affected by the assumption (0.22 percent of total VOL tank population).

Economists have analyzed factors that determine changes in consumption of an input into a production process when the price of that input is rising.* In this case, storage tanks are productive inputs into processes that produce or consume VOL or into provision of storage services. The four factors that influence consumption of storage tanks are:

1. The degree to which consumption of the good produced using storage tanks is affected by increases in its price.
2. The degree to which other inputs can be used to substitute for storage tanks.
3. The proportion of total production costs accounted for by storage tanks.
4. The degree to which price of other inputs into the production process affects their supply.

The less these factors apply, the less likely increases in price of storage tanks due to a regulatory alternative will significantly impact quantity of tanks purchased in any future period. Each of the four factors is discussed below for VOL storage tanks.

First, Tables 9-4 and 9-5 show that during the late 1970s output of chemicals (in physical units) was fairly stable. As Tables 9-4 and 9-5 also show, the price of these chemicals was increasing more rapidly than was general inflation. This increase suggests that for VOLs as a group response of consumption to a price increase is fairly small. The qualifier "as a group" is important in this context because most good substitutes for VOLs are also likely to be VOLs. Therefore, storage of substitutes also would be subject to the standards.

Second, no low-cost means of providing the same storage service provided by affected tanks appears readily available, especially with terminals, whose principal purpose is storage. Most bulk VOL storage tanks either already have been or, under the regulatory alternatives, are about to be affected by such standards. Therefore, it is not feasible to substitute uncontrolled tanks for controlled tanks. The cost advantage large tanks enjoy (see Chapter 8) probably will also sharply limit substitution of uncontrolled small-volume tanks for the large-volume tanks affected by the regulatory alternatives. Finally, VOL storage service is a crucial part of production and consumption of VOLs in that it is nearly a fixed component of plant design.

---

*Responsiveness of storage tank consumption to price of tanks is called "own price elasticity of demand" by economists. The four factors that determine this elasticity for an input to a production process were first hypothesized by Alfred Marshall. A detailed and more formal discussion of those factors as modified by other economists may be found in Layard and Walters.[34]

Third, the share of VOL storage costs in production of VOLs or VOL products is also likely to be small. In the model producer/consumer plant described in Chapter 6, capital costs for VOL storage comprise 2 to 11 percent of total capital costs (depending on the regulatory alternative) and at most just over 1 percent of total annual capital and operating costs. However, for VOL storage terminals, share of tank costs in total costs is likely to be somewhat higher, perhaps as much as 50 percent of total costs.

Fourth, although supply responsiveness to price for other factors used with VOL storage tanks is more difficult to generalize, recent world experience suggests that at least in one critical input category for VOL producers--petroleum or petrochemicals--supply is relatively insensitive to price in the short run.

Based upon these considerations, this economic impact analysis adopts the working assumption that consumption of VOL storage tanks is not responsive to price changes of the magnitude that would be due to the regulatory alternatives. This demand condition is depicted in Figure 9-2 as a vertical demand curve, D_1. In the event that the price of tanks rises from P to P', consumption of tanks and, hence, number of impacted VOL storage tanks will remain unchanged at the rate T_t^i per year. This characterization of tank demand is recognized to be extreme in that, as noted above, at least some reduced consumption is observed in response to price increases for most commodities. However, no data on prices and quantities of VOL storage tanks that can be used to estimate directly price responsiveness of VOL storage tanks are publicly available. Furthermore, if demand is treated in this way, the likely direction of any error associated with this assumption is known. That is, the impact of each regulatory alternative on VOL storage cost is overestimated because if any price responsiveness is assumed, fewer new tanks would be projected and subject to the standards and additional cost.

As illustrated by demand schedule D_2 in Figure 9-2, the economic analysis allows for economic growth by specifying a shift in demand for VOL storage tanks over time. As the economy grows, some growth will occur in demand for VOL chemicals and, hence, for new and replacement VOL storage tanks. The magnitude of this growth between periods t and t+1 is reflected in demand curves for the respective periods and the difference $T^i_{t+1} - T^i_t$. The 5-percent growth rate in new tank capacity demand and the tank replacement schedule, adopted for projections in Subsection 9.1, is also adopted as the quantitative expression of these shifts in demand.

As discussed above, data on the impacted VOL tank population for each regulatory alternative, year, pressure interval, and volume interval determine the value of T^i_t in Figure 9-2. The regression equations of cost against volume estimated in Chapter 8 for each regulatory alternative are now used to determine change in price of a tank in that volume interval, P' - P.* Multiplying T^i_t by P' - P gives an estimate of the area P'abP in Figure 9-2. This is the estimated investment impact, in 1982 dollars, of a particular regulatory alternative on tanks in the given volume interval in the year t. These values are then summed over all volume intervals to obtain the regulatory alternative's nationwide investment impact in year t. Finally, annual investment values for the years 1984 to 1988 are summed to estimate cumulative nationwide investment impact for the projection period.

Table 9-21 presents resulting data on nationwide investment impacts for each regulatory alternative using this methodology. Investment impacts for Regulatory Alternatives II and III are the same because they are estimated in Chapter 8 to have the same impact on a tank's cost. For comparison, estimated investment in new VOL tanks covered by the baseline conditions (>75 m^3 and >3.5 kPa) exclusive of vapor recovery equipment or pressure vessel costs also is included. This comparison shows that the additional investment required by

---

*The change in price in this analysis is equivalent to a change in cost because tank fabricators will not contract to build new tanks unless their costs are covered by the price (see Subsection 9.2.1, above). For regression equations expressed in terms of diameter, an equivalent volumetric relationship was derived using a correspondence between diameter and height suggested by Reference 36. The change in cost or price for any volume interval is estimated by using the mid-point of that interval in the regression equation. For the interval that is unboundered (>15,000 m^3), a volume of 20,000 m^3 was used.

TABLE 9-21. ADDITIONAL NATIONWIDE INVESTMENT IN VOL STORAGE REQUIRED BY THE REGULATORY ALTERNATIVES, 1984 to 1988

	Estimated investment under baseline assumptions[a,b] ($$10^6$, constant 1982 dollars)	Additional nationwide investment[b] ($$10^6$, in constant 1982 dollars)			
Year		I	II & III	IV	V
1984	41.94	2.70	2.75	4.70	21.67
1985	43.86	2.87	2.93	4.96	22.69
1986	44.31	2.93	2.99	5.04	22.97
1987	45.92	3.07	3.14	5.27	23.84
1988	52.04	3.39	3.46	5.86	26.84
1984-1988	224.57	14.84	15.16	25.54	116.13

---

[a] An estimate of nationwide investment that would be made in new tanks with volumes > 75 m^3 containing liquids with vapor pressures > 3.5 kPa without implementing any regulatory alternatives. This estimate is exclusive of any investment in vapor recovery equipment or pressure vessels.

[b] Annual values are not discounted to the present.

all regulatory alternatives except V is dwarfed by expected expenditures on the tanks: $3 million/yr to $6 million/yr of additional investment for Regulatory Alternatives I - IV relative to $42 million/yr to $52 million/yr investment under the baseline. The absolute magnitude of these expenditures is, likewise, small relative to the size of the industry.

9.2.4 Nationwide Annualized Cost Impacts.

Total annual cost of each of the regulatory alternatives depends on the number of new tanks put in place over the 5-year period and the change in each tank's annualized cost. Annualized cost represents the annual financial obligations imposed by the regulatory alternative on purchasers of VOL storage tanks. In particular, fifth-year costs include payments related to the regulatory alternatives in the fifth year for debt and operating expenses associated with tanks purchased in each of the 4 previous years as well as expenses newly incurred due to tank purchases in the fifth year. These costs, in constant 1982 dollars, are presented in the second column of Table 9-22. These costs are based upon capital and operating costs for individual tanks presented in Chapter 8, projections of new tanks by year made in Subsection 9.1.7, and impacted tank percentages by volume and pressure discussed in Subsection 9.2.3. They range from $3.3 million for Regulatory Alternative I to just over $26 million for Regulatory Alternative V.

As discussed above, tanks impacted by the regulatory alternatives also will generate additional economic benefits for tank users because they reduce vaporization of valuable VOLs. Tank owners are better off by the amount of emission reductions times the value of the chemical saved. Nationwide emission reductions for each regulatory alternative in the fifth year after promulgation are estimated in Chapter 7. The $460/Mg estimate of value of VOL was applied to these emission reductions to estimate nationwide economic benefit of this emission reduction to VOL tank users in 1988. Resulting emission savings credit was then applied against annualized costs; results are shown in column 3 of Table 9-22. On a nationwide basis, the first three regulatory alternatives produce net economic benefits in 1988 when an emission savings credit is included in the calculation. The fact that nationwide annual costs are negative is not inconsistent with the finding of positive costs of these alternatives for the two model plants because the model plants were selected to exhibit a greater than average economic impact.

TABLE 9-22. FIFTH-YEAR NATIONWIDE ANNUALIZED COST OF REGULATORY ALTERNATIVES

Regulatory alternative	Fifth-year annualized cost ($\$10^6$, in constant 1982 dollars) Without emission savings credit	With emission savings credit[a]
I	3.25	-0.56
II	3.34	-0.67
III	3.34	-1.01
IV	6.11	1.68
V	26.14	21.61

[a] Credit computed based on a VOL price of $460/Mg.

9.3 REGULATORY, INFLATIONARY, SOCIOECONOMIC, AND SMALL-BUSINESS IMPACTS

9.3.1 Executive Order (E.O.) 12291

E.O. 12291 requires performance of a regulatory impact analysis of a proposed regulation if that regulation is likely to result in

1. An annual effect on the economy of $100 million or more.
2. A major cost or price increase for consumers; individual industries; Federal, State, or local Government agencies; or geographic regions.
3. Significant adverse effects on competition, employment, investment, productivity, innovation, or ability of United States-based enterprises to compete with foreign-based enterprises in domestic or foreign markets.

Estimated nationwide investment on tank purchases impacts listed in Table 9-21 show that, for all years from 1983 through 1988 and all regulatory alternatives, the investment impact would be substantially less than $100 million/yr. When capital costs associated with the regulatory alternatives are annualized and credit is given for reduced VOL vaporization, it is estimated that the first three regulatory alternatives actually generate nationwide cost savings in 1988 (see Table 9-22). Regulatory Alternatives IV and V show nationwide annualized cost increases after credit for emission savings of $\$1.68 \times 10^6$ and $\$21.61 \times 10^6$, respectively. These are very small figures compared to the investment and sales levels of VOL-storing industries.

Percentage price increases for the model terminal are higher than those for a model producer/consumer but are still less than 5 percent for Regulatory Alternatives I through IV after emission reductions credits. Regulatory Alternative V is estimated to increase the price of storage at the model terminal by 13.2 percent without an emission reduction credit and by 11.8 percent with such a credit.

Based on these results, the proposed standards do not qualify as major regulatory alternatives under the criteria enumerated above: the annual effect on the economy is substantially less than $100 million, the price impacts are small, and the standard will not affect operation of the domestic economy or its international trade significantly. Therefore, a regulatory impact analysis and associated benefit/cost calculations need not be performed. However, it is still worthwhile to note, in a qualitative fashion, the benefits against which costs discussed above should be balanced.

The standards will reduce the emission rate of VOLs to the atmosphere. These compounds are precursors of photochemical oxidants, particularly ozone. The EPA publication Air Quality Criteria for Ozone and Other Photochemical Oxidants[37] explains the effects of exposure to elevated ambient concentrations of oxidants. (Ozone depletion of the upper atmosphere and its relation to this standard are not addressed here.) These effects include:

1. Human health effects. Ozone exposure has been shown to cause increased rates of respiratory symptoms such as coughing, wheezing, sneezing, and shortness of breath; increased rates of headaches, eye irritation, and throat irritation; and physiological damage to red blood cells. One experiment links ozone exposure to human cell damage known as chromosomal aberrations.
2. Vegetation effects. Ozone reduces citrus, grape, cotton, and other crop yields by damaging leaves and plants. Reduction has been shown to be linked to level and duration of ozone exposure.
3. Materials effects. Ozone exposure has been shown to accelerate deterioration of organic materials such as plastics and rubber (elastomers), textile dyes, fibers, and certain paints and coatings.
4. Ecosystem effects. Continued ozone exposure has been linked to disappearance of trees such as Ponderosa and Jeffrey Pines and death of predominant vegetation. Hence, continued ozone exposure places stress on the ecosystem.

In addition to reducing the severity of physical and biological effects enumerated above, the regulatory action is likely to improve the aesthetic and economic value of the environment by beautifying natural and undeveloped land through increased vegetation, improved visibility, and reduced incidence of noxious odors.

9.3.2 The Regulatory Flexibility Act

The Regulatory Flexibility Act (P.L. 96-354, September 19, 1980) requires that special consideration be given to the impact of a proposed regulation on small businesses, organizations, and governmental units. In particular, the Act requires a regulatory flexibility analysis if a substantial number of small firms are impacted adversely by the regulatory alternatives examined.

In Chapter 6, the model independent terminal and model producer/consumer were identified as small facilities. The economic impact of Regulatory Alternatives I through IV were not found to be significant, especially when product recovery credits for emission control were considered. Under Regulatory Alternative IV with recovery credits, the model independent terminal was estimated to require a price increase of 0.043 ¢/kg (or 4.3 percent) of VOL stored. Under Regulatory Alternative IV with recovery credits, the model producer/consumer was estimated to require a price increase of 0.14 ¢/kg (or 0.3 percent) of VOL. Investments required were correspondingly small: for Regulatory Alternative IV, an additional $71,800 (in 1982 dollars) investment would be required of the model independent terminal and a $23,200 (in 1982 dollars) investment would be required by the model producer/consumer. These represent relatively small increments to investments required for the new facilities as a whole.

9.4 REFERENCES

1. Scherer, F.M. Industrial Market Structure and Economic Performance. 2nd Ed. Chicago, Rand McNally College Publishing Company, 1980.
2. Hegman, George B. In: World Outlook for Petrochemicals. Cambridge, Arthur D. Little, Inc., August 1978. p. 7.
3. U.S. Department of Commerce, Bureau of the Census. 1977 Census of Manufactures. Part 2, SIC Major Groups 27-34. U.S. Government Printing Office. Washington, DC. 1981. p. 28F-13.
4. Booz, Allen, and Hamilton, Inc. Cost of Hydrocarbon Emissions Control to the U.S. Chemical Industry (SIC 28). Exhibit VI-6. Florham Park, NJ. December 1977.
5. U.S. Department of Commerce, Bureau of Economic Analysis. 1972 Input-Output Tables: Structure of the U.S. Economy. Vol. II. U.S. Government Printing Office. Washington, DC. 1979.
6. U.S. Department of Commerce, Bureau of the Census. 1972 Census of Manufactures. Volume II, Industrial Statistics, Part 2, SIC Major Group 27-34. U.S. Government Printing Office. Washington, DC. p. 28F-13 to 28F-15. August 1976.
7. Memorandum from Rockstroh, M., TRW to Smith, V., RTI. July 10, 1980.
8. Independent Liquid Terminals Association. 1982 Bulk Liquid Terminals Directory, 7th Edition. Washington, DC. 1982. 99 p.
9. Fallwell, William F. Chemical Capital Spending to Turn up in 1979. Chemical and Engineering News. 56:10-12. December 11, 1978.
10. Reference 3, p. 28F-5, 28B-5.
11. U.S. Department of Commerce, Bureau of the Census. Business Statistics, 1977. U.S. Government Printing Office. Washington, DC. March 1978. p. 5.
12. Reference 6, p. 28F-5, 28B-5.
13. Operating Rates. Chemical and Engineering News. 56:59. June 11, 1979.

14. U.S. International Trade Commission. U.S. Production and Sales--Synthetic Organic Chemicals (for the years 1955 through 1981). Table 1. U.S. Government Printing Office. Washington, DC.

15. U.S. Department of Commerce, Bureau of Industrial Economics. 1982 U.S. Industrial Outlook. U.S. Government Printing Office. Washington, DC. January 1982. p. 102-103.

16. Reference 15, p. 120, 141, 316.

17. Radian Corporation. Organic Chemical Producers Data Base, 1976. Research Triangle Park, NC. Contract No. 68-02-2623. 1978.

18. Reference 6, p. 28F-8, 28F-9.

19. Reference 3, p. 28F-7, 28F-8.

20. Reference 6, p. 28B-7, 28B-8.

21. Reference 3, p. 28B-8, 28B-9.

22. U.S. Department of Labor, Bureau of Labor Statistics. Producer Prices and Price Indexes. Supplements 1978-1982 (data for 1977 to 1981). U.S. Government Printing Office. Washington, DC.

23. U.S. Environmental Protection Agency. VOC Fugitive Emissions in Synthetic Organic Chemicals Manufacturing Industry-Background Information for Proposed Standards. Research Triangle Park, NC. EPA-450/3-80-033a. November 1980. p. 9-1 to 9-36, E-1 to E-11.

24. U.S. Environmental Protection Agency. Fugitive Emission Sources of Organic Compounds--Additional Information on Emissions, Emission Reductions, and Costs. Research Triangle Park, NC. EPA-450/3-82-010. April 1982. p. A-1 to A-23.

25. Telecon. Anderson, Don, RTI, with Thayer, Mark, Predicast, Inc. October 29, 1982.

26. Predicasts, Inc. Predicasts Basebook. Cleveland, OH. 1979.

27. Hydroscience, Inc. Emissions Control Options for the Synthetic Organic Chemicals Manufacturing Industry: Storage Handling Report (Draft). Knoxville, TN. March 1979.

28. Reference 7.

29. Telecon. Anderson, Don, RTI, with Greek, Bruce, American Chemical Society. October 29, 1982.

30. Telecon. Anderson, Don, RTI, with Pfann, Harry, Department of Commerce. October 29, 1982.

31. Memorandum from Rockstroh, M.A., TRW, to Moody, W.T., TRW. February 1, 1980.

32. Radian, Inc. The Revised Organic Chemical Producers Data Base System, Final Interim Report. Austin, Texas. EPA Contract No. 68-03-2623. March 31, 1979.

33. Letter from Shumaker, J., TRW, to Morris, G.E., RTI. January 3, 1983.

34. Layard, P.R.G., and A.A. Walters. Microeconomic Theory. New York, McGraw-Hill Book Company, 1978. p. 260-270.

35. Memorandum from Moody, W.T., TRW, to Morris, G.E., RTI, December 17, 1982.

36. Air Quality Criteria for Ozone and other Photochemical oxidants. U.S. Environmental Protection Agency. Publication No. EPA-600/8-78-004. April 1978.

APPENDIX A — EVOLUTION OF THE BACKGROUND INFORMATION DOCUMENT

A1. Literature Review

November 1978	Hydroscience Inc. Emission Control Options for the Synthetic Organic Chemicals Industry - Storage and Handling Report, October, 1979.
November 22, 1978	Letter with attached report from Kern, R. C. November 22, 1978, Ultraflote, to R. K. Burr, EPA:CPB, Hydrocarbon Emission Loss Measurements on a 20 Foot Diameter Pilot Test Tank with an Ultraflote and a CBI Weathermaster Internal Floating Roof.
December 1979	Letter and attachment from Lee, B., Radian Corporation, to Moody, W. T., TRW:EED. November 30, 1979. Letter transmitting updated version of the report generated August 1978 from the Organic Chemical Producers Data Base.
January 1980	Evaporation Loss in the Petroleum Industry - Causes and Control, Evaporation Loss Committee, American Petroleum Institute, February 1959.
January 1980	Evaporation Loss from Floating-Roof Tanks, Evaporation Loss Committee, American Petroleum Institute, February 1962.
January 1980	Petrochemical Evaporation Loss from Storage Tanks, Division of Refining, American Petroleum Institute, November 1969.
January 1980	Venting Atmospheric and Low-Pressure Tank (Nonrefrigerated and Refrigerated), Refining Department, American Petroleum Institute, December 1973.
January 1980	Use of Internal Covers and Covered Floating Roofs to Reduce Evaporation Loss, American Petroleum Institute, 1976.
January 1980	Measurement and Determination of Hydrocarbon Emissions in the Course of Storage and Transfer in Above-Ground Fixed Cover Tanks With and Without Floating Covers, BMI-DGMK Projects 4590-10 and 4590-11, Translated for EPA by Literature Research Company, 1976.
January 1980	Hydrocarbon Emissions from Floating Roof Petroleum Tanks, Western Oil and Gas Association, January 1977.

January 1980	Cost of Hydrocarbon Emissions Control to the U.S. Chemical Industry (SIC 28), Volumes I and II, Manufacturing Chemists Association, December 1977.
February 1980	Control of Volatile Organic Emissions from Storage of Petroleum Liquids in Fixed-Roof Tanks, EPA-450/2-77-036, EPA:CPB, December 1977.
February 1980	Evaluation of Hydrocarbon Emissions from Petroleum Liquid Storage, EPA-450/3-78-012, R. K. Burr, EPA:CPB, March 1978.
February 1980	Suggested Emission Factors for Fixed-Roof Storage Tanks, A. L. Wilson, Engineering-Science, Inc., November 13, 1978.
February 1980	Control of Volatile Organic Emissions from Petroleum Liquid Storage in External Floating Roof Tanks, EPA-450/2-78-047, EPA:CPB, December 1978.
April 1980	The Revised Organic Chemical Producers Data Base System, EPA Contract No. 68-02-2623 (Radian Corporation), A. Jefcoat, EPA:IERL, March 31, 1979.
March 1980	Comments on the "BMI-DGMK" Report, J. Zabaga, Mobile Oil Company, June 16, 1978.
June 1980	Bulk Liquid Terminals and Storage Facilities, Independent Liquid Terminals Association, 1979 (Directory).
June 1980	Emissions Control Options for the Synthetic Organic Chemicals Manufacturing Industry, Thermal Oxidation, (Draft), EPA Contract No. 68-02-2577, EPA:ESED, December 1979.
June 1980	Emissions Control Options for the Synthetic Organic Chemicals Manufacturing Industry, Carbon Adsorption (Draft), EPA Contract No. 68-02-2577, EPA:ESED, February 1980.
June 1980	Emissions Control Options for the Synthetic Organic Chemicals Manufacturing Industry, Thermal Oxidation Supplement (Draft), EPA Contract No. 68-02-2577, EPA:ESED, February 1980.

A2. Information from Other Sources

January 1979	H. F. Ellenburg, Instrumentation Products Co., to L. Hayes, TRW:EED, December 20, 1978, Letter with enclosed information on vapor recovery systems for storage tanks and solvent transfer facilities.
April 1979	T. W. Mix, Merix Corporation to R. K. Burr, EPA:CPB, April 21, 1979, Letter with enclosed summary print-out of input and output losses of above-ground gasoline tanks on farms.
September 1979	B. Lee, Radian Corporation, to W. T. Moody, TRW:EED, August 31, 1979, Letter with enclosed information from the Organic Chemical Producers Data Base.
October 1979	J. K. Walters, American Petroleum Institute, to R. K. Burr, EPA:CPB, September 14, 1979, Letter with enclosed technical comments of the American Petroleum Institute on the draft report "Measurement of Benzene Emissions from a Floating Roof Test Tank."
December 1979	M. Rutland, GATX, to R. Guidetti, TRW:EED, December 3, 1979, Letter concerning budgetary prices for standard API-650 Cone Roof Tanks and Floating Roof Tanks.
December 1979	E. B. Dees, TRW:EED, to M. R. Frega, Frega Associates, Inc., December 6, 1979, Letter requesting information to be used in an industry profile for volatile organic liquids storage.
March 1980	H. Reiss, Altech Industries, Inc., to G. May, TRW:EED, February 26, 1980, Letter with summarized budget price information.
March 1980	T. P. Tremblay, Chicago Bridge & Iron Company, to W. T. Moody, TRW:EED, February 27, 1980, Letter concerning price differentials Weathermaster Floating Roof Tank versus cone roof tank-revision 1.0.
March 1980	T. T. Fung, Systems Division, to M. A. Rockstroh, TRW:EED, March 14, 1980, Letter concerning acetone storage tank emissions control study.
April 1980	J. J. Dechant, Brown Boiler & Tank Works, Ltd., to TRW:EED, March 27, 1980, Letter concerning quotation with budget figures in order to erect acetone storage tanks.

May 1980	J. R. Farmer, EPA:CPB, to R. L. Stuart, Monsanto Company, April 28, 1980, Letter with enclosed background information to support the volatile organic liquids regulation with attached list of addressees.
May 1980	Comments on the Volatile Organic Liquids Background Information, H. D. Kerfman, GATX, May 1980.
June 1980	L. P. Hughes, Mobay Chemical Corporation, to W. T. Moody, TRW:EED, May 29, 1980, Letter with enclosed responses regarding possible tank emission recovery systems.
June 1980	Dr. F. S. Lisella, Department of Health and Human Services, to J. R. Farmer, EPA:CPB, June 2, 1980, Letter commenting on the draft copy of Volatile Organic Compound Emissions from Volatile Organic Liquid Storage Tanks.
June 1980	R. E. Kinghorn, R.F.I. Services Corp., to W. T. Moody, TRW:EED, June 9, 1980, Letter concerning prices for conventional cone roof tanks constructed to API 650 code.
June 1980	T. P. Tremblay, Chicago Bridge & Iron Company, to W. T. Moody, TRW:EED, June 22, 1980, Letter concerning price differentials Weathermaster Floating Roof Tank versus cone roof tank.
July 1980	R. Harrison, Western Oil and Gas Association, to J. R. Farmer, EPA:ESED, June 27, 1980, Letter commenting on the draft document "Volatile Organic Compound Emissions from Volatile Organic Liquids Storage Tanks."
July 1980	J. K. Walters, American Petroleum Institute, to J. R. Farmer, EPA:ESED, June 30, 1980, Letter commenting on the draft document "Volatile Organic Compound Emissions from Volatile Organic Liquids Storage Tanks."
October 1982 to December 1982	Updated costs of control equipment obtained from 15 vendors.
January 1983	W. F. O'Keefe, American Petroleum Institute (API) to S. R. Wyatt, EPA:ESED, Letter concerning emissions calculations (including final API Bulletin 2519 evaporation loss from internal floating roof tanks).

A3. Emission Source Measurement

May 1979	Emission Measurements on a Floating Roof Pilot Test Tank, R. J. Laverman, Chicago Bridge & Iron Company, May 16, 1979.
June 1979	Measurement of Benzene Emissions from a Floating Roof Test Tank, EPA-450/3-79-020, R. K. Burr, EPA:CPB, June 1979.
August 1979	Hydrocarbon Emission Measurements of Crude Oil on the 20 Foot Diameter Floating Roof Pilot Test Tank, R. J. Laverman, Chicago Bridge & Iron Company, August 15, 1978.
March 1982	Testing Program to Measure Hydrocarbon Emissions From A Controlled Internal Floating Roof Tank, for American Petroleum Institute Committee on Evaporative Loss Measurement Task Group 2519, R. J. Laverman, T. J. Haynie, and J. F. Newbury, Chicago Bridge & Iron Company, March 1982.

A4. Plant and Other Related Trips

November 14-17, 1978	Trip to Hydroscience Inc., to discuss data base and Phase I report.
November 15, 1978	Trip to Exxon Chemicals, Baton Rouge, Louisiana, to obtain information on the rail car loading facility.
November 15, 1978	Trip to Gilmore Maxine Services, Baton Rouge, Louisiana, to inspect a barge cleaning facility.
August 14, 1980	Trip to Conoco Chemical, Baltimore, Maryland, to inspect a vapor recovery system.
August 20, 1980	Trip to Vulcan Materials, Geismar, Louisiana, to inspect a vapor recovery system.
August 21, 1980	Trip to Amoco Chemical, Texas City, Texas, to inspect a vapor recovery system.
August 26, 1980	Trip to Dow Chemical, Midland, Michigan, to inspect two vapor recovery systems.

A5. Meetings with Industry

March 20, 1979	Meeting with Dow Chemical Corporation to discuss small vessel (≅20,000 gallon) control techniques and industry trends.
August 9, 1979	Meeting with the Chemical Manufacturers Association to discuss the regulatory approach and control technologies.
January 26, 1982	Meeting with the American Petroleum Institute (API) to discuss the new API preliminary testing data available on floating roof vessel emissions.
September 2, 1982	Meeting with the American Petroleum Institute to discuss 1) the analytical approach used by API in developing storage vessel emission factors for the Bulletin 2519 "Evaporative Loss from Internal Floating Roof Tanks"; 2) the EPA approach for emission factors development; and 3) the effect of roof configuration upon emissions.
December 15, 1982	Meeting with the American Petroleum Institute to discuss EPA study and review of internal floating roof vessel emissions and the API testing program.

A6. Reports and Review Process

December 14, 1978	J. L. Shumaker, EPA:CPB, to V. Smith, Research Triangle Institute, Letter concerning the finalization of SOCMI to be used in all generic standards.
January 29, 1979	E. C. Pulaski, TRW:EED, to V. Smith, Research Triangle Institute, Letter with enclosed model facilities for synthetic organic chemical storage facilities.
March 14, 1979	R. C. Weber, EPA:CPB, to E. Pulaski, TRW:EED, Letter confirming deletion of Handling portion or SOCMI Storage and Handling NSPS.
August 1979	Decision to expand SOCMI storage to VOL.
November 29, 1979	W. T. Moody, TRW:EED, to the Volatile Organic Liquids Docket Files, Memo with an attached selection of Model Facilities.
January 18, 1980	W. T. Moody, TRW:EED, to the Volatile Organic Liquids Docket Files, Memo concerning tanks involved in industrial organics.
March 26, 1980	Model Plants and Regulatory Alternatives are finalized.
June 20, 1980	Decision on the basis of the standard.
October 1980	Working Group Review.
December 3, 1980	National Air Pollution Control Techniques Advisory Committee Meeting.
December 1980	Steering Committee Review.
April 2, 1981	Assistant Administrator Review.
October 1981	Package withdrawn from review process and returned to OAQPS.
March 1983	Steering Committee review of the revised standard based upon newly available emissions information.
June 1983	Assistant Administrator Review.

APPENDIX B - INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

Table B-1. INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

Agency Guidelines for Preparing Regulatory Action Environmental Impact Statements (39 FR 37419)	Location Within the Background Information Document (BID)
1. Background, description, and purpose of the regulatory alternatives and the statutory authority.	The regulatory alternatives from which standards will be chosen are summarized in Chapter 1, Section 1.1.
The relationship to other actions and proposals significantly affected by the regulatory alternatives.	To the extent possible, other EPA regulations and OSHA regulations which apply to the affected industries are detailed in Chapter 8, Section 8.5 and are considered in the economic impact study in Chapter 9.
Industry affected by the regulatory alternatives.	The industry and emission sources within the industry affected by the regulatory alternatives are listed in Chapter 3.
Specific processes affected by the regulatory alternatives.	The specific processes and facilities affected by the regulatory alternatives are summarized in Chapter 3, Section 3.2.
Applicable control technologies	The control technologies which can be applied to reduce VOC emissions from storage tanks and the emission reductions which have been achieved by these control technologies are described in detail in Chapter 4.
2. Alternatives to the action.	The various categories of alternatives to the actions which were considered are listed below. a. Alternative regulatory approaches. The alternative approaches for regulating VOC emissions under Section 111 of the Clean Air Act are outlined in Chapter 6. b. Alternative control devices. The alternative control devices that could be required by the regulatory alternatives and the reasons for selecting these particular alternatives are outlined in Chapter 4.

(continued)

Table B-1. Continued

Agency Guidelines for Preparing Regulatory Action Environmental Impact Statements (39 FR 37419)	Location Within the Background Information Document (BID)
Agency's comparative evaluation of the beneficial and adverse environmental, health, social, and economic effects of each reasonable alternative.	a. A discussion of the Agency's comparative evaluation of the various alternative regulatory approaches for VOC emissions from VOC storage vessels can be found in Chapter 7, 8, and 9. b. A summary of the beneficial and adverse environmental effects of the regulatory alternatives can be found in Chapter 7. A detailed description of the cost of each alternative control level, including the capital and annualized costs, can be found in Chapter 8. The socioeconomic impacts of the regulatory alternatives including potential plant closures and maximum price increases in consumer products, can be found in Chapter 9.
3. Environmental impact of the regulatory alternatives.	
a. Primary impact.	
Primary impacts are those that can be attributed directly to the action, such as reduced levels of specific pollutants brought about by a new standard and the physical changes that occur in the various media with this reduction.	Air impact analysis shows the primary impacts in Chapter 7, Section 7.2.

(continued)

Table B-1. Concluded

Agency Guidelines for Preparing Regulatory Action Environmental Impact Statements (39 FR 37419)	Location Within the Background Information Document (BID)
b. Secondary impact.	
Secondary impacts are indirect or induced impacts. For example, mandatory reduction of specific pollutants brought about by a new standard could result in the adoption of control technology that exacerbates another pollution problem and would be a secondary impact.	Other environmental impacts of the individual controls that can be used to meet the regulatory alternatives are identified qualitatively in Chapter 7, Sections 7.3, 7.4, and 7.5. The secondary water impacts of the alternative control levels are quantified in Chapter 7, Section 7.3. The energy consumption impact of the alternative control levels is quantified in Chapter 7, Section 7.4.
4. Other considerations.	
a. Adverse impacts which cannot be avoided should a regulatory alternative be implemented.	A summary of the potential adverse environmental and health impacts of the regulatory alternatives and a discussion of the significance of each impact can be found in Chapter 7. Factors which already exist to eliminate some of the potential adverse impacts are identified. Those adverse impacts that are unavoidable are also identified, along with any steps which can be taken to minimize them.
b. Irreversible and irretrievable commitments of resources that would be involved with the regulatory alternatives, should one be implemented.	Irreversible and irretrievable resources that would be involved in the proposed action are discussed in Chapter 7, Section 7.5.1.

APPENDIX C

EMISSIONS SOURCE TEST DATA AND ANALYSIS

APPENDIX C - EMISSIONS SOURCE TEST DATA AND ANALYSIS

This appendix provides a summary description of the emission tests conducted on internal floating roof (IFR) tanks and the major results. For additional and complete information, refer to the referenced reports.

C.1 TEST PROCEDURES

All emissions test measurements were obtained by Chicago Bridge and Iron Company (CBI) under contract to the American Petroleum Institute.[1] The test program was divided into two broad components: pilot tank test measurements and internal floating roof tank component measurements. The primary goal of the pilot tank tests was to determine emissions from IFR seal systems and deck seams; while the purpose of the IFR component tests was to determine emissions from IFR fittings (hatches, ladder wells, etc.) and to investigate other issues such as the permeability of seal systems to the stored hydrocarbon.

C.1.1 Pilot Test Tank Emission Measurements

C.1.1.2 Description of Test Facility. The tests were performed in a test IFR tank at CBI's research facility in Plainfield, Illinois. The test tank was 20 feet in diameter and had a 9-foot shell height (see Figure C-1). The lower 5'3" of the tank shell was provided with a heating/cooling jacket through which a heated or cooled water/ethylene glycol mixture was continuously circulated to control the product temperature. The effect of air blowing through the shell vents was simulated by means of a blower connected to the tank by a 12-inch diameter duct. This air exited from the tank through a similar duct.

Based on wind tunnel tests, it has been possible to determine the pressure coefficient, C_p, variation over the exterior surface of the tank. The air flow rate through the vents over the internal floating roof was then related to C_p by means of a mathematical model.[1] Thus,

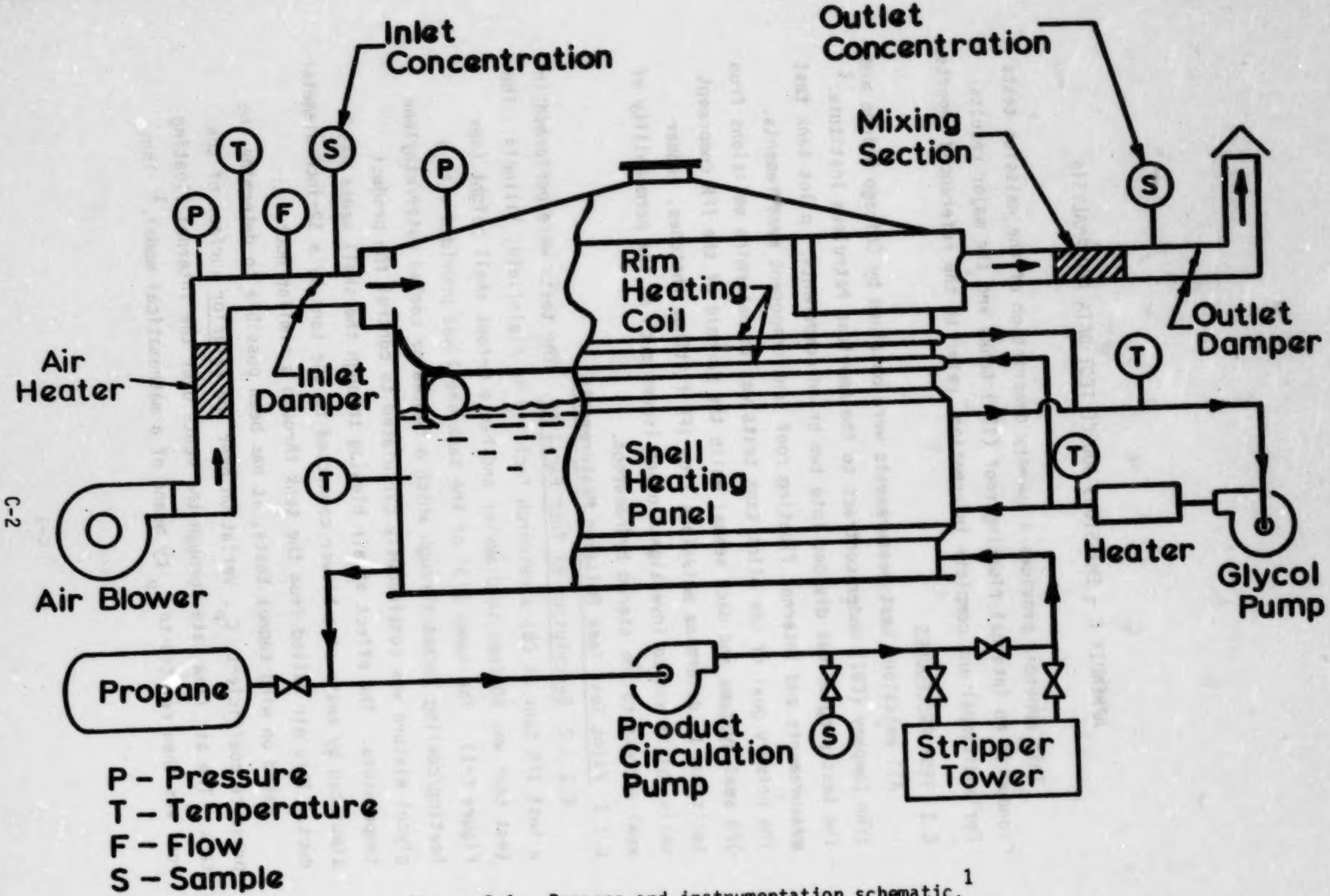

Inlet Concentration
Outlet Concentration
Mixing Section
P
T
F
S
P
S
Rim Heating Coil
Outlet Damper
Air Heater
Inlet Damper
T
T
Shell Heating Panel
T
Heater
Glycol Pump
Air Blower
Propane
Product Circulation Pump
S
Stripper Tower
P - Pressure
T - Temperature
F - Flow
S - Sample

Figure C-1. Process and instrumentation schematic.[1]

internal air flow could be related to ambient wind speed emissions. During each test, emissions were measured at several equivalent ambient wind speeds. The recorded data included the inlet and outlet total hydrocarbon content, system temperatures, and the inlet air flow rate.

C.1.1.3 Pilot Test Tank Internal Floating Roofs and Liquids. Tests were conducted in three IFR types, and three seal systems. The first IFR tested (Phase 1, 1R) was a bolted noncontact IFR, equipped with a wiper type primary seal, and on some tests a secondary seal (Figures C-2 and C-3). In some tests gaps were intentionally placed between the seal and the tank shell. Seal gaps were either of 1 or 3 square inches of gap per-foot-of-tank-diameter. In some instances, 0.020 inch thick polyurethane-coated nylon fabric, which was taped in place using aluminum-backed duct tape, was used to seal off certain emission sources.

The second IFR tested (Phase 2, 2R) was a welded contact IFR equipped with a liquid-mounted, foam filled seal (Figures C-4 and C-5). As in Phase 1, a secondary seal was in place during some tests; the effects of seal gaps on emissions were investigated; and emission areas were sealed during some tests.

The final IFR (Phase 3, 3R) was a bolted contact type deck, equipped with a vapor-mounted, foam-filled primary seal, and (during some tests) a foam-filled secondary seal (Figures C-6 and C-7).

In each phase, three different test liquids were employed. The test liquids were a propane/octane mixture, hexane, and octane.

During Phase 1, the primary seal was replaced after Test No. 13. The primary seal was again replaced at the beginning of Phase 1R (Test API 73). Each of the primary seals had the same construction.

The initial Phase 1 tests indicated that emissions might vary as a function of the inlet air-product temperature difference. To control for this, a heater was installed in the inlet air duct after Test API 19. Table C-1 displays the test conditions for all Phase 1, 1R tests.

Table C-2 displays the test conditions for the Phase 2, 2R tests. There was a problem with product seepage through a thermocouple during Tests API 35 through API 44. However, it was possible to correct the results to account for this problem. Additionally Test API 51 was performed at the much higher air flow rates that simulate an external floating roof tank.

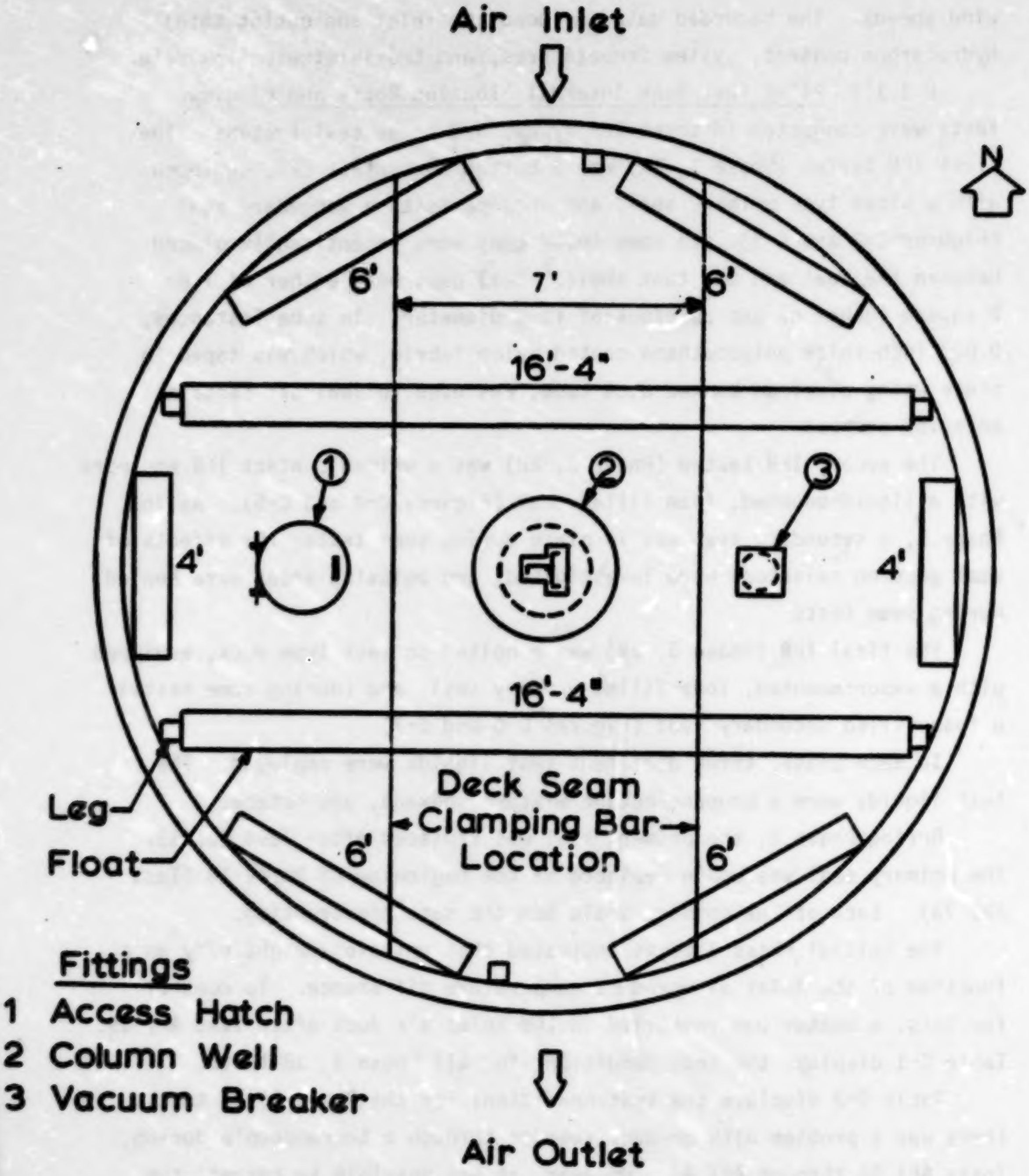

Air Inlet
N
6'
7'
6'
16'-4"
1
2
3
4'
I
4'
16'-4"
Deck Seam
Clamping Bar
Location
Leg
Float
6'
6'
Fittings
1 Access Hatch
2 Column Well
3 Vacuum Breaker
Air Outlet

Figure C-2. Plan view of noncontact bolted IFR.[1]

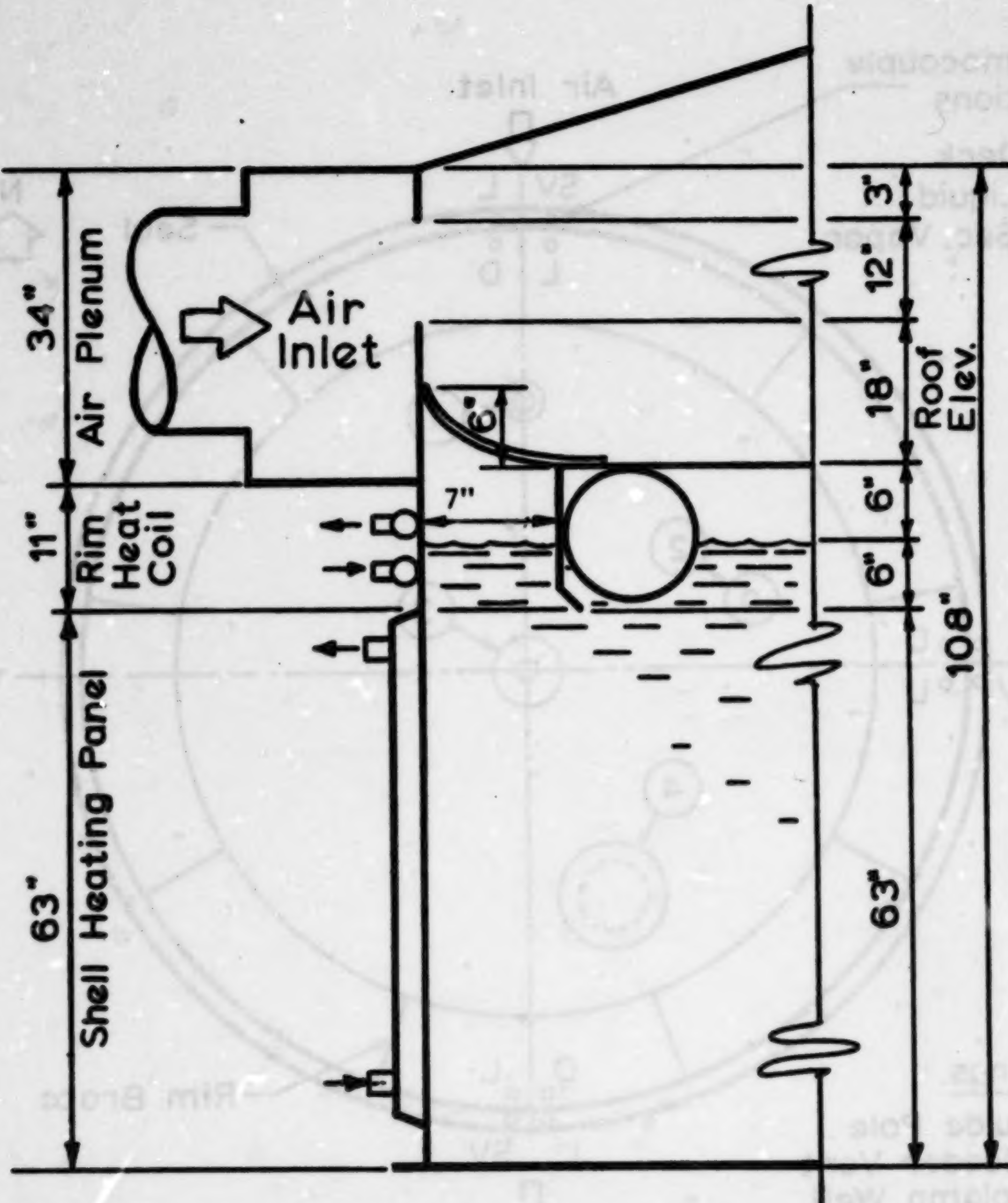

34"
Air Plenum
Air Inlet
11"
Rim Heat Coil
63"
Shell Heating Panel
7"
6"
3"
12"
18"
6"
6"
63"
Roof Elev.
108"

Figure C-3. Elevation view of noncontact bolted IFR in test tank.[1]

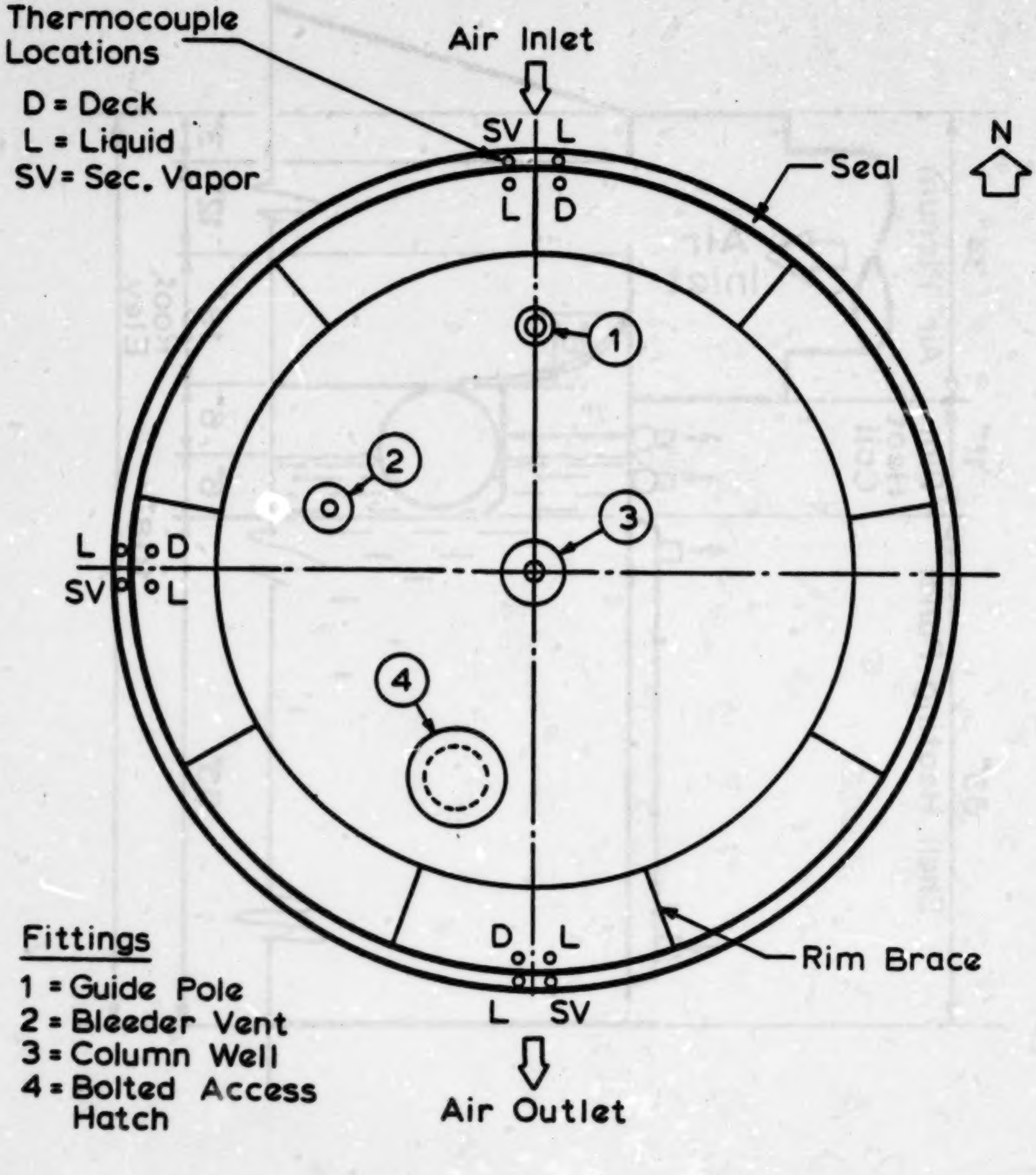

Thermocouple Locations
D = Deck
L = Liquid
SV = Sec. Vapor
Air Inlet
N
SV
L
L
D
Seal
1
2
3
4
L
D
SV
L
D
L
L
SV
Rim Brace
Fittings
1 = Guide Pole
2 = Bleeder Vent
3 = Column Well
4 = Bolted Access Hatch
Air Outlet

Figure C-4. Plan view of contact welded IFR.[1]

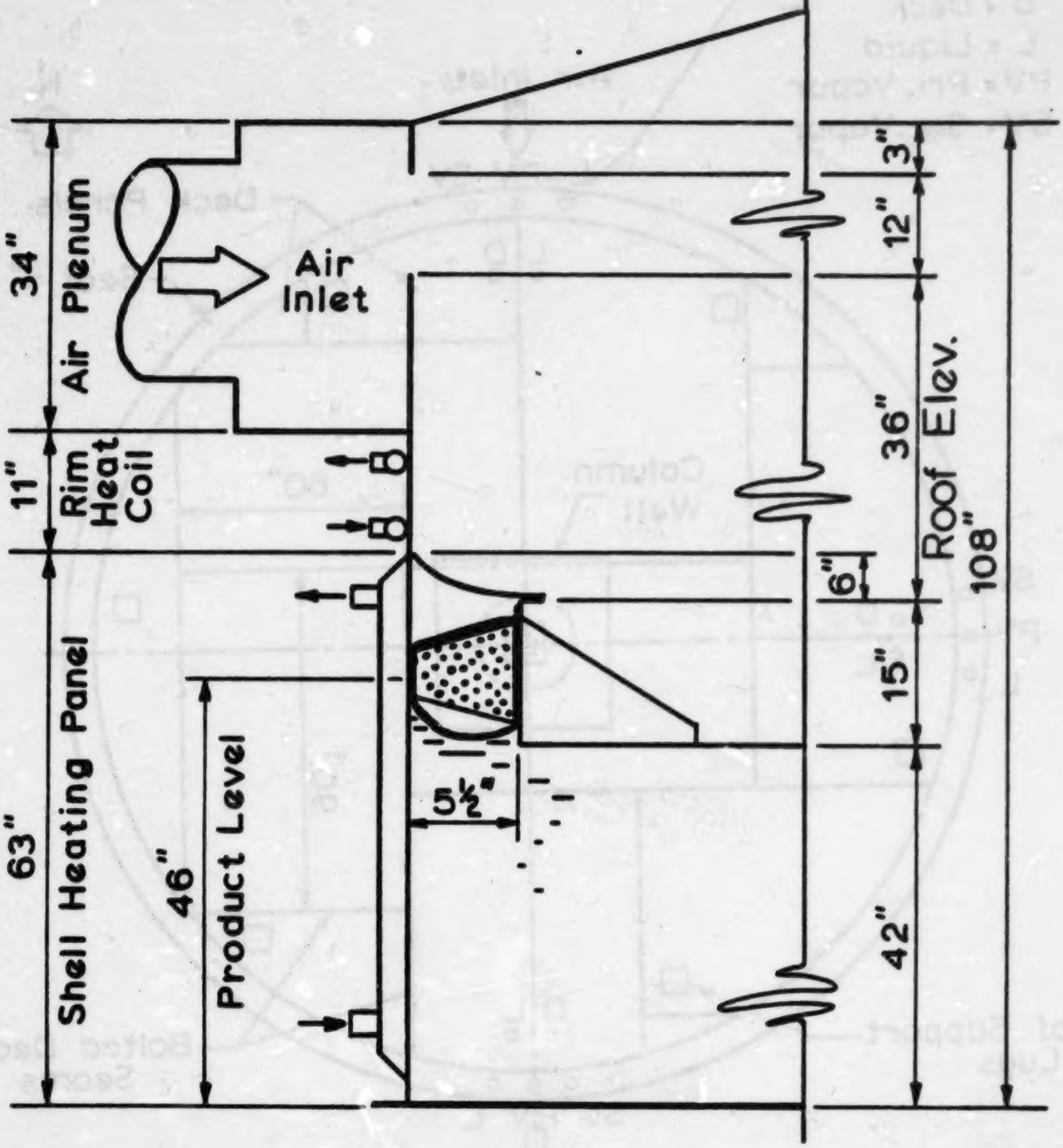

34"
Air Plenum
Air Inlet
11"
Rim Heat Coil
63"
Shell Heating Panel
46"
Product Level
5½"
3"
12"
36"
6"
15"
42"
Roof Elev.
108"

Figure C-5. Elevation view of contact welded IFR in test tank.[1]

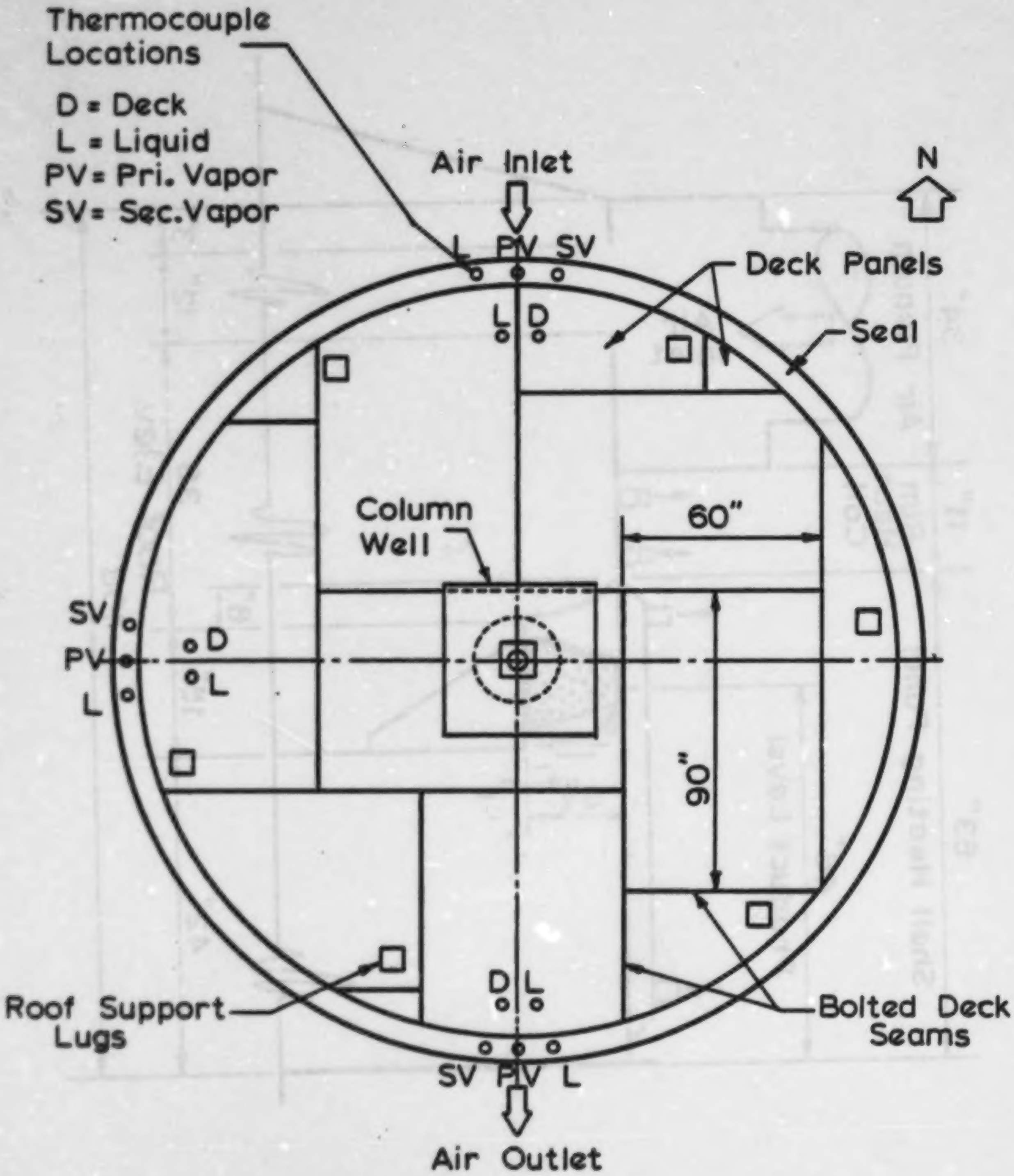

Thermocouple Locations
D = Deck
L = Liquid
PV = Pri. Vapor
SV = Sec. Vapor
Air Inlet
N
L
PV
SV
L
D
Deck Panels
Seal
Column Well
60"
SV
PV
D
L
L
90"
Roof Support Lugs
D
L
Bolted Deck Seams
SV
PV
L
Air Outlet

Figure C-6. Plan view of contact bolted IFR.[1]

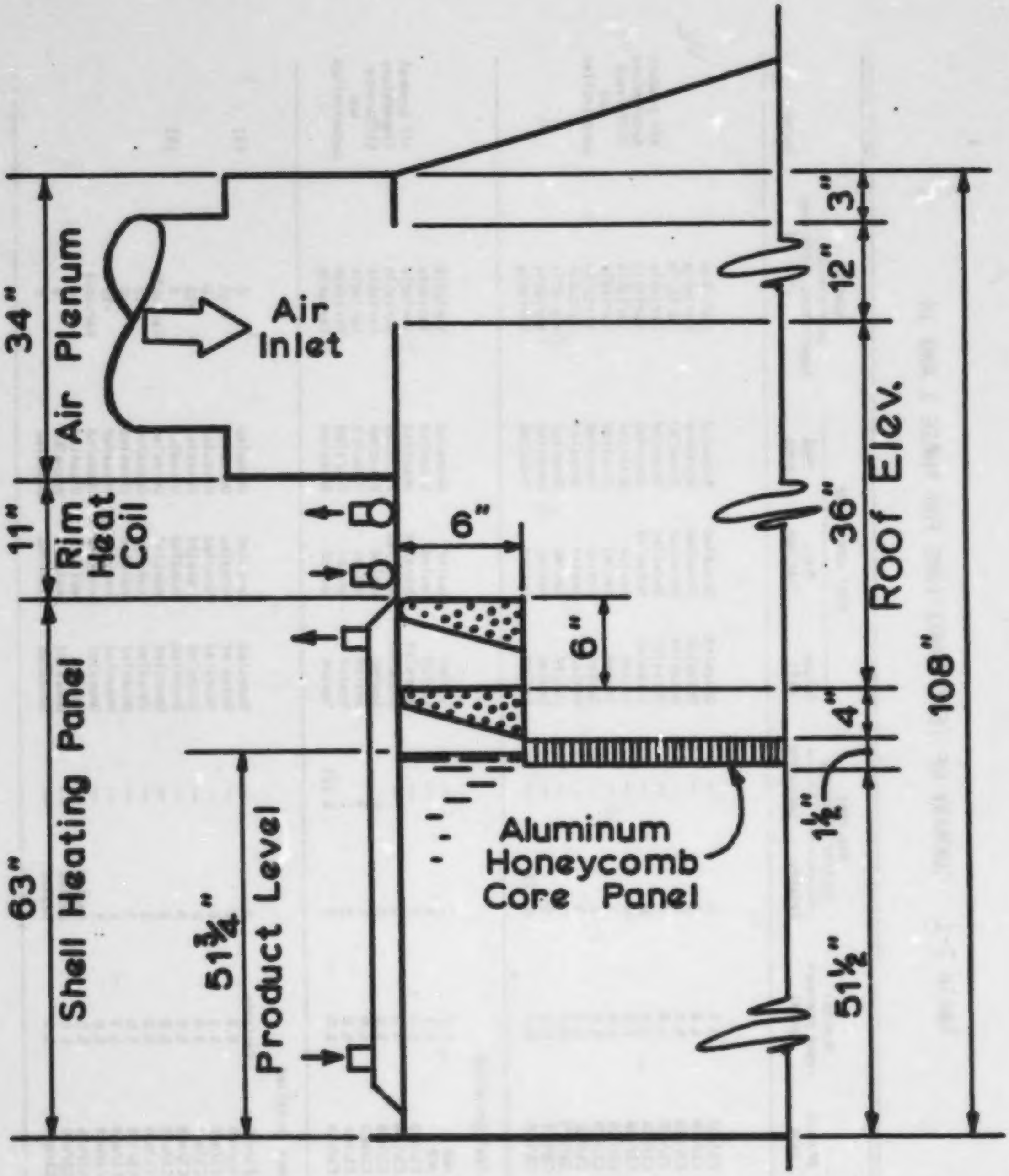

34"
Air Plenum
Air Inlet
11"
Rim Heat Coil
6"
6"
63"
Shell Heating Panel
51¾"
Product Level
Aluminum Honeycomb Core Panel
3"
12"
36"
Roof Elev.
4"
1½"
51½"
108"

Figure C-7. Elevation view of contact bolted IFR in test tank.[1]

Table C-1. SUMMARY OF TEST CONDITIONS FOR PHASE 1 AND 1R

Test number	Product type	Nominal vapor pressure (psia)	Gap area (in^2/ft diameter)		Roof components			Nominal (air-product) temperature difference (°F)	Notes
			Primary	Secondary	Column well	Deck fittings	Deck seams		
Phase 1:									
API 1	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	
API 2	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	
API 3	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	
API 4	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	Air product temperature difference was uncontrolled
API 5	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	
API 6	C3/nC8	5.0	0	—	Sealed	Sealed	Unsealed	Variable	
API 7	C3/nC8	5.0	1	—	Sealed	Sealed	Unsealed	Variable	
API 8	C3/nC8	5.0	3	—	Sealed	Sealed	Unsealed	Variable	
API 9	C3/nC8	0.5	3	—	Sealed	Sealed	Unsealed	Variable	
API 10	C3/nC8	0.5	1	—	Sealed	Sealed	Unsealed	Variable	
API 11	C3/nC8	0.5	0	—	Sealed	Sealed	Unsealed	Variable	
API 12	C3/nC8	0.5	0 (1)	—	Sealed	Sealed	Unsealed	Variable	
New Primary Seal Installed									
API 13	nC8	0.5	0	—	Sealed	Sealed	Unsealed	Variable	
API 14	nC8	0.5	1	—	Sealed	Sealed	Unsealed	Variable	
API 15	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	Air product temperature difference was uncontrolled
API 16	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	
API 17	C3/nC8	5.0	0	0	Sealed	Sealed	Unsealed	Variable	
API 18	C3/nC8	5.0	3	0	Sealed	Sealed	Unsealed	Variable	
API 19	C3/nC8	5.0	3	1	Sealed	Sealed	Unsealed	Variable	
API 19A	C3/nC8	5.0	3	1 (2)	Sealed	Sealed	Unsealed	Variable	
Air Duct Heater Installed									
API 20	C3/nC8	Variable	0	—	Unsealed	Unsealed	Unsealed	0	(3)
API 21A	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	-15	
API 21B	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	0	
API 21C	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	+15	
API 21D	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	0	(4)
API 21E	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	
API 22A	C3/nC8	5.0	1	—	Unsealed	Unsealed	Unsealed	-15	
API 22B	C3/nC8	5.0	1	—	Unsealed	Unsealed	Unsealed	0	
API 22C	C3/nC8	5.0	1	—	Unsealed	Unsealed	Unsealed	+15	
API 22D	C3/nC8	5.0	1	—	Unsealed	Unsealed	Unsealed	Variable	
API 23	C3/nC8	5.0	Sealed	—	Sealed	Sealed	Unsealed	0	
API 24	C3/nC8	5.0	Sealed	—	Unsealed	Sealed	Unsealed	0	
API 25	C3/nC8	5.0	Sealed	—	Unsealed	Unsealed	Unsealed	0	

(continued)

Table C-1. Concluded

Test number	Product type	Nominal vapor pressure (psia)	Gap area (in²/ft diameter)		Roof components			Nominal (air-product) temperature difference (°F)	Notes
			Primary	Secondary	Column well	Deck fittings	Deck seams		
API 26A	C3/nC8	3.5	1	—	Unsealed	Unsealed	Unsealed	0	
API 26B	C3/nC8	2.5	1	—	Unsealed	Unsealed	Unsealed	0	
API 27A	C3/nC8	0.5	1	—	Unsealed	Unsealed	Unsealed	-15	
API 27B	C3/nC8	0.5	1	—	Unsealed	Unsealed	Unsealed	0	
API 27C	C3/nC8	0.5	1	—	Unsealed	Unsealed	Unsealed	+15	
API 28	C3/nC8	0.5	0	—	Unsealed	Unsealed	Unsealed	0	
API 29	nC8	0.5	1	—	Unsealed	Unsealed	Unsealed	0	(5)
API 29R	nC8	0.5	1	—	Unsealed	Unsealed	Unsealed	0	
API 30	nC8	0.5	0	—	Unsealed	Unsealed	Unsealed	0	(5)
API 30R	nC8	0.5	0	—	Unsealed	Unsealed	Unsealed	0	
API 31	nC8	0.5	1	0	Unsealed	Unsealed	Unsealed	0	
API 31A	nC8	0.5	1	0	Unsealed	Unsealed	Unsealed	+15	
API 32	nC6	2.5	0	—	Unsealed	Unsealed	Unsealed	0	
API 33	nC6	2.5	1	—	Unsealed	Unsealed	Unsealed	0	
API 33A	nC6	2.5	1	—	Unsealed	Unsealed	Unsealed	+15	
API 34	nC6	2.5	1	—	Unsealed	Unsealed	Unsealed	0	
API 34A	nC6	2.5	1	—	Unsealed	Unsealed	Unsealed	+15	
Phase 1R:									
API 73	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	0	(7)
API 73A	C3/nC8	5.0	0	—	Unsealed(6)	Unsealed	Unsealed	0	
API 74	C3/nC8	5.0	0	—	Unsealed(6)	Unsealed	Unsealed	0	
API 75	C3/nC8	5.0	3	—	Unsealed(6)	Unsealed	Unsealed	0	
API 76	C3/nC8	5.0	Sealed	—	Sealed	Sealed	Unsealed	0	
API 76R	C3/nC8	5.0	Sealed	—	Sealed	Sealed	Unsealed	0	
API 77	C3/nC8	5.0	Sealed	—	Sealed	Sealed	Sealed	0	

Notes: (1). Seal closure devices were installed to eliminate all unintentional gaps.
(2). Gaps in the secondary seal were rotated 45° to position them directly above the primary seal gaps.
(3). Emission test data is questionable due to variable product temperature causing nonequilibrium conditions.
(4). Emission test data is questionable due to nonequilibrium condition in the rim vapor space due to prior air purge.
(5). Emission test data is questionable due to air inlet heater control problems.
(6). A column well gasket was used during this test.
(7). Emission test data is questionable due to nonequilibrium condition of product caused by insufficient mixing.

Table C-2. SUMMARY OF TEST CONDITIONS FOR PHASE 2 AND 2R (1)

Test number	Product type	Nominal vapor pressure (psia)	Gap area (in^2/ft diameter)		Roof components		Notes
			Primary	Secondary	Column well	Deck fittings	
Phase 2							
API 35	C3/nC8	5.0	0	-	Unsealed	Unsealed	(2)
API 36	C3/nC8	5.0	1	-	Unsealed	Unsealed	(2)
API 37	C3/nC8	5.0	0	-	Unsealed	Unsealed	(2)
API 38	C3/nC8	5.0	0.5	-	Unsealed	Unsealed	(2)
API 39	C3/nC8	5.0	3	-	Unsealed	Unsealed	(2)
API 40	C3/nC8	5.0	1	-	Unsealed	Unsealed	(2)
API 41	C3/nC8	5.0	0	0	Sealed	Sealed	(2)
API 42	C3/nC8	5.0	1	0	Sealed	Sealed	(2)
API 43	C3/nC8	5.0	3	1	Sealed	Sealed	(2)
API 44	C3/nC8	5.0	Sealed	-	Sealed	Sealed	(2)
Repaired Product Seepage Through Thermocouple Fitting							
API 45	C3/nC8	5.0	Sealed	-	Sealed	Sealed	
API 46	C3/nC8	5.0	Sealed	-	Unsealed	Sealed	
API 47	C3/nC8	5.0	Sealed	-	Unsealed	Unsealed	
API 48	C3/nC8	5.0	0	-	Unsealed	Unsealed	
API 49	C3/nC8	5.0	0	-	Sealed	Sealed	
API 50	nC8	0.5	1	-	Unsealed	Unsealed	(3)
API 51	nC8	0.5	1	-	Unsealed	Unsealed	(3), (4)
Phase 2R							
API 67A	nC8	0.5	1	-	Unsealed	Unsealed	(3)
API 67	nC8	0.5	1	-	Unsealed	Unsealed	
API 68	nC6	2.5	1	-	Unsealed	Unsealed	
API 69	nC6	2.5	1	0	Unsealed	Unsealed	
API 70	C3/nC8	5.0	1	0	Unsealed	Unsealed	
API 71	C3/nC8	5.0	1	-	Unsealed	Unsealed	
API 71A	C3/nC8	5.0	1	-	Unsealed	Unsealed	(5)
API 72	C3/nC8	2.5	1	-	Unsealed	Unsealed	

Notes:
(1). During both Phases 2 and 2R, nominal (air-product) temperature difference was kept at zero.
(2). Product seepage through a thermocouple fitting occurred during this test.
(3). Product contained trace amount of propane.
(4). During this test the air flow rate was increased to simulate an external floating roof.
(5). During this test the inlet air and product heaters were turned off, and the wind speed was kept constant at about 10 mi/hr.

Table C-3 displays the test conditions of Phase 3 and 3R. During some tests product penetrated the primary seal. The problem was repaired, and the tests were repeated.

Table C-4 presents the results of all relevant tests. In summary, it was found that an air product temperature differential of up to 15F° had no significant effect on emissions. Small gaps (1 inch^2/feet diameter) did not appear to affect emissions significantly. Also, the tests demonstrate that ambient wind (particularly at speeds less than 20 miles per hour) has little or no effect on emissions.

C.1.1.4 IFR Component Tests.

C.1.1.4.1 Deck fitting emission tests. To quantify emissions from various types of fittings, a series of bench scale tests were performed. These fittings were placed through the top cover of a liquid-filled drum, and the drum was then placed on a scale. The weight change and other data were recorded over a 30 day period. Figure C-8 displays a sample bench test, and Table C-5 summarizes the results.

C.1.1.4.2 Permeability tests. A series of bench permeability tests were performed to determine the permeability of the 0.020 inch-thick polyurethane-coated nylon fabric to various hydrocarbon liquids. One laboratory test was also performed. Also included was a test on the same fabric of 0.037 inch thickness with benzene as a test liquid. This material had been used as the seal envelop material in Phase 2 and 2R, and in earlier test work.[2] The results are shown in Table C-6.

C.2 MAJOR RESULTS

This section discusses the major results of the analysis of test work. Although the relationship of emission factors to the test results is discussed, the actual development of emission factors is presented elsewhere.[3]

C.2.1 Seal Losses

Total measured emissions in a given tank test are the sum of all of the emission sources in that test. Therefore, to develop an emission factor the results must be reduced. For example, the permeation emissions through any sealing material, fittings, and any other source that is not of interest must be accounted for, and subtracted out before the emissions from the component of interest are known. Because of this reduction process, component emissions factors cannot be read directly from Table C-4.

Table C-3. SUMMARY OF TEST CONDITIONS FOR PHASE 3 AND 3R (1)

Test number	Product type	Nominal vapor pressure (psia)	Gap area (in^2/ft diameter) Primary	Gap area (in^2/ft diameter) Secondary	Roof components Column well	Roof components Deck seams	Roof components Rim plate	Notes
Phase 3								
API 52A	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	(2)
API 52B	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	(2)
API 52C	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	(2)
API 52D	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	(2)
API 52E	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	(2), (3)
API 53A	C3/nC8	5.0	1	0	Unsealed	Unsealed	Unsealed	(2)
API 53B	C3/nC8	5.0	1	0	Unsealed	Unsealed	Unsealed	(2)
API 53C	C3/nC8	5.0	1	0	Unsealed	Unsealed	Unsealed	(2)
API 54A	C3/nC8	5.0	3	1	Unsealed	Unsealed	Unsealed	(2)
API 54B	C3/nC8	5.0	3	1	Unsealed	Unsealed	Unsealed	(2)
Product Liquid Removed From Primary Seal								
API 52	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	
API 52R	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	
API 53	C3/nC8	5.0	1	0	Unsealed	Unsealed	Unsealed	
API 54	C3/nC8	5.0	3	1	Unsealed	Unsealed	Unsealed	
API 55A	C3/nC8	5.0	Sealed	Sealed	Sealed	Sealed	Sealed	
API 55	C3/nC8	5.0	Sealed	Sealed	Sealed	Sealed	Sealed	(4)
API 56	C3/nC8	5.0	Sealed	Sealed	Sealed	Unsealed	Sealed	(4)
API 57	C3/nC8	5.0	Sealed	Sealed	Sealed	Unsealed	Unsealed	(4)
API 58	C3/nC8	5.0	Sealed	Sealed	Unsealed	Unsealed	Unsealed	(4)
API 59	C3/nC8	5.0	0	-	Unsealed	Unsealed	Unsealed	
API 60	C3/nC8	5.0	1	-	Unsealed	Unsealed	Unsealed	
API 61	C3/nC8	5.0	3	-	Unsealed	Unsealed	Unsealed	
API 62	C3/nC8	2.5	1	-	Unsealed	Unsealed	Unsealed	
API 63	C3/nC8	0.5	1	-	Unsealed	Unsealed	Unsealed	
API 64	nC8	0.5	1	-	Unsealed	Unsealed	Unsealed	
API 65	nC6	2.5	1	-	Unsealed	Unsealed	Unsealed	
Phase 3R								
API 65R	nC6	2.5	1	-	Unsealed	Unsealed	Unsealed	
API 65A	nC6	2.5	1	-	Unsealed	Unsealed	Unsealed	(5)
API 66	nC6	2.5	1	0	Unsealed	Unsealed	Unsealed	(2)
API 66R	nC6	2.5	1	0	Unsealed	Unsealed	Unsealed	

Notes:
(1). During both Phases 3 and 3R, Type 1 air flow distribution was used, the nominal (air-product) temperature difference was kept at zero, and the roof elevation was kept at 63 inches below the air inlet.
(2). Emission test data is of questionable value since liquid product was present in the prime y seal.
(3). Column well cover intentionally positioned off center with a gap.
(4). All taped joints were also caulked during this test.
(5). During this test the primary seal gap plates were intentionally extended down into the product.

Table C-4. SUMMARY OF TEST RESULTS FOR ALL POTENTIALLY RELEVANT TESTS

CBI test number	Nominal true vapor pressure[1] (psia)	Average emissions lb-mole/day
API-1	5.00	0.283
API-2	5.00	0.423
API-3	5.00	0.309
API-4	5.00	0.449
API-5	5.00	1.33
API-7	5.00	0.224
API-8	5.00	0.439
API-12	0.50	0.0181
API-13	0.50	0.0605
API-14	0.50	0.0668
API-13R	0.50	0.0567
API-13, 13R	0.50	0.059
API-14R	0.50	0.196
API-14, 14R	0.50	0.159
API-16	5.00	0.926
API-17	5.00	0.0698
API-18	5.00	0.110
API-19	5.00	0.134
API-19A	5.00	0.147
API-21A	5.00	0.101
API-21B	5.00	0.0891
API-21C	5.00	0.0909
API-21AR	5.00	0.171
API-21A, AR	5.00	0.129
API-21BR	5.00	0.140
API-21B, BR	5.00	0.102
API-21CR	5.00	0.133
API-21C, CR	5.00	0.108
API-22A	5.00	0.142
API-22BI	5.00	0.165
API-22D	5.00	0.124
API-22B	5.00	0.176
API-22BI, B	5.00	0.173
API-22C	5.00	0.211
API-21E	5.00	0.128
API-23	5.00	0.0714
API-24	5.00	0.120
API-25	5.00	0.108
API-26A	5.00	0.117
API-26B	5.00	0.128
API-27A	0.50	0.030

(continued)

Table C-4. Continued

CBI test number	Nominal true vapor pressure[1] (psia)	Average emissions lb-mole/day
API-27B	0.50	0.0196
API-27C	0.50	0.0553
API-28	0.50	0.0167
API-30	0.50	0.0316
API-29R	0.50	0.143
API-31	0.50	0.0357
API-31A	0.50	0.0256
API-32	2.50	0.0232
API-33	2.50	0.0306
API-33A	2.50	0.0251
API-34	2.50	0.0317
API-34A	2.50	0.0347
API-35	5.00	0.0366
API-36	5.00	0.0359
API-37	5.00	0.0297
API-38	5.00	0.0334
API-39	5.00	0.0492
API-39R	5.00	0.0387
API-40	5.00	0.0301
API-41	5.00	0.0154
API-42	5.00	0.0176
API-43	5.00	0.0269
API-44	5.00	0.0149
API-45	5.00	0.00693
API-46	5.00	0.00928
API-47	5.00	0.0170
API-48	5.00	0.0246
API-49	5.00	0.0188
API-50	0.50	0.00426
API-51	0.50	0.0390
API-52	5.00	0.0376
API-53P	5.00	0.0407
API-54	5.00	0.0400
API-53	5.00	0.0372
API-53P, 53	5.00	0.0399
API-55	5.00	0.0156
API-56	5.00	0.0338
API-57	5.00	0.0345
API-58	5.00	0.0433
API-52R	5.00	0.0435
API-52, 52R	5.00	0.0400
API-59	5.00	0.0536

(continued)

Table C-4. Concluded

CBI test number	Nominal true vapor pressure[1] (psia)	Average emissions lb-mole/day
API-60	5.00	0.0574
API-61	5.00	0.0690
API-62	5.00	0.0649
API-63R	0.50	0.00930
API-64	0.50	0.00867
API-65	2.50	0.0242
API-66	2.50	0.0378
API-66R	2.50	0.0322
API-65R	2.50	0.0407
API-65A	2.50	0.0417
API-67A	0.50	0.00779
API-67	0.50	0.00500
API-68	2.50	0.0105
API-69	2.50	0.00715
API-70	5.00	0.0202
API-71	5.00	0.0247
API-72	5.00	0.040
API-73	5.00	0.0466
API-73A	5.00	0.0628
API-74	5.00	0.0627
API-75	5.00	0.0730
API-76	5.00	0.0509
API-76R	5.00	0.0433
API-76, 76R	5.00	0.0484
API-77	5.00	0.0417

[1] Nominal average true vapor pressure (TVP) is the TVP at which the emissions were calculated by using the vapor pressure function to normalize the measured hydrocarbon concentration to the concentration expected at the nominal TVP.

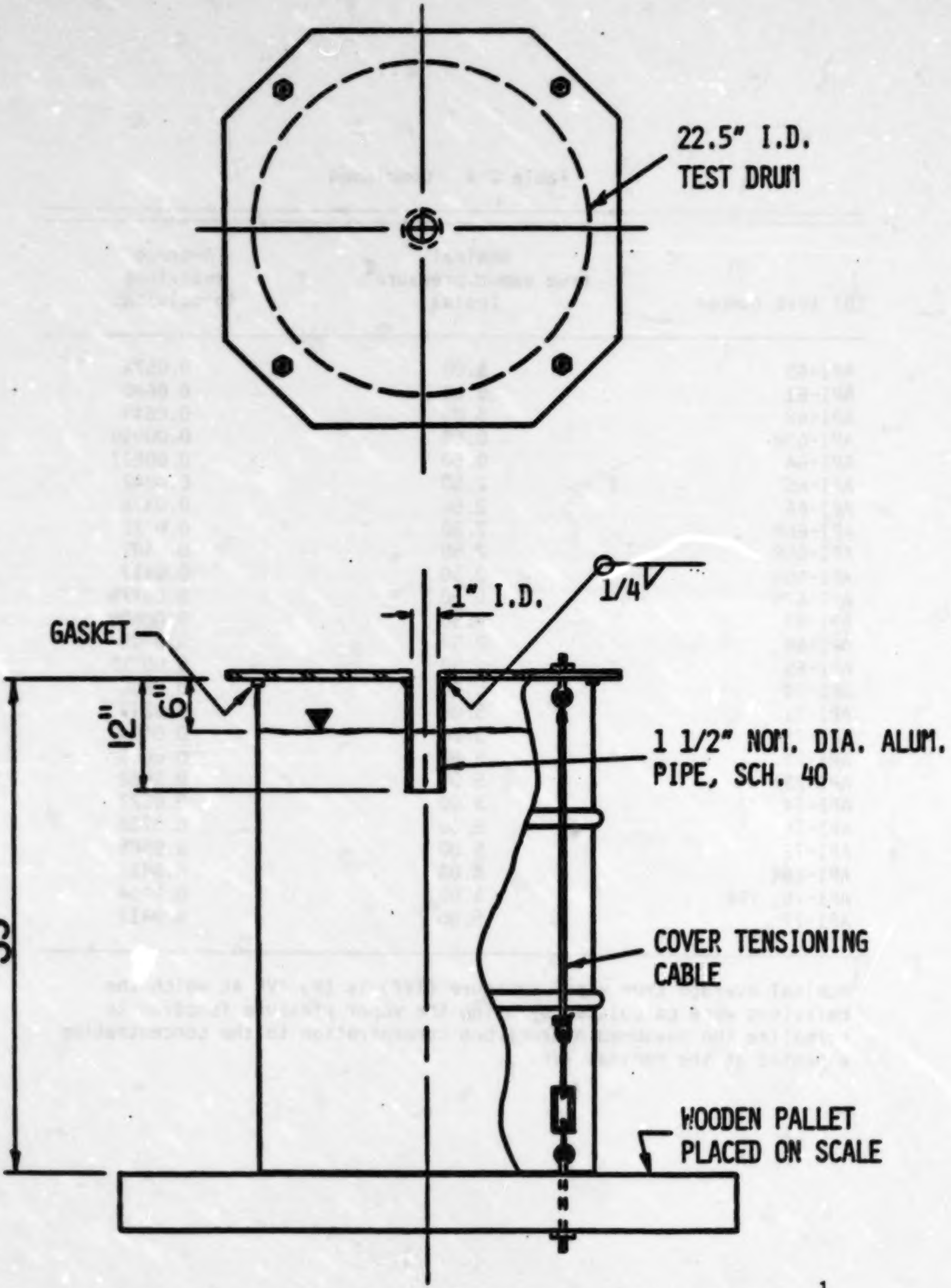

22.5" I.D.
TEST DRUM
1" I.D.
1/4
GASKET
6"
12"
1 1/2" NOM. DIA. ALUM. PIPE, SCH. 40
35"
COVER TENSIONING CABLE
WOODEN PALLET PLACED ON SCALE

Figure C-8. Example of fitting emission bench test apparatus.[1]

Table C-5. SUMMARY OF IFR DECK FITTING EMISSION TESTS

Test number	Description	Product type	Correlation coefficient (-)	Average emission rate (2) (lb mole/yr)
1	Access hatch cover, ungasketed	nC6	0.681	0.204
2	Access hatch cover, gasketed and clamped	nC6	0.689	0.158
3	1½ inch diameter adjustable roof leg	nC6	0.914	0.977
4	8 inch diameter slotted pipe sample well	nC6	0.996	4.69
5	8 inch diameter pipe column well	nC6	0.989	2.11
6	1 inch diameter stub drain	nC6	0.902	0.279
7	Phase 1 column well, ungasketed	nC6	0.998	4.32
8	½ inch gap around built-up column	nC6	0.998	5.42
9A	Phase 1 column well, gasketed	C3/nC8	0.977	3.38
9B	Phase 1 column well, ungasketed	C3/nC8	0.959	5.07
10	Phase 2 column well	C3/nC8	0.964	1.22
11	Phase 3 column well (1)	C3/nC8	0.986	2.25
12	1/8 inch gap around built-up column	nC6	0.983	2.44
13	Access hatch cover with 1/8 inch gap	nC6	0.997	5.61
14	Sample well with 10% gap area	nC6	0.985	1.45
15	1/8 inch gap around built-up column (1)	nC6	0.983	2.81

Notes: (1). Test drum was 30 in. diameter.
(2). Average emission rate normalized to a nominal vapor pressure of 5.00 psia.

Table C-6. PERMEABILITY OF POLYURETHANE COATED NYLON FABRIC

Test number	Fabric thickness (in)	Fabric area (ft^2)	Length of taped seams (in)	Product type	Average product temperature (°F)	Average vapor pressure (psia)	Vapor mole weight (lbm/lbmole)	Average emission rate (lbm/day)	Correlation coefficient (-)	Average rate (lbm/ft^2 day)	Notes
16	0.020	2.75	--	C3/nC8	59.2	7.13	45.8	0.0612	0.838	0.0222	
17	0.037	2.75	--	C6H6	60.5	1.22	78.1	0.159	0.996	0.0578	
18	0.037	2.75	--	nC6	60.1	1.98	86.2	0.0158	0.663	0.00578	
19	0.020	2.75	--	C3/nC8	53.8	3.86	46.6	0.0652	0.783	0.0237	
20	0.020	2.75	--	C3/nC8	48.1	3.56	46.3	0.0808	0.806	0.0294	
21	0.020	2.75	48	C3/nC8	50.9	4.68	45.9	0.0650	0.863	0.0236	(1)
22	0.020	2.75	--	C3/nC8	43.2	3.59	46.0	0.0344	0.805	0.0125	
23	1/16" thk aluminum		60	C3/nC8	44.2	3.38	46.3	0.00273	0.096	--	(1)
Laboratory Permeability Test											
--	0.020	0.467	--	nC6	74.8	1.85	86.2	0.0244	--	0.0522	

Notes: (1). Aluminum backed duct tape was used on all taped seams.

For seal systems, it was found that

$$E_s = K_r \; Mw \; D \; P^* \qquad \text{(C-1)}$$

Where:

E_s = Emissions from the seal area in lbs/day
K_r = Seal factor
Mw = Molecular weight of vapor
D = Tank diameter
P^* = Vapor pressure function

The reduced emissions from seals of similar construction and gap condition are averaged together. A seal emission factor is the weighted average of the averaged reduced emissions. Weights are selected according to field survey data that relate seal gap area to frequency of occurrence. The emission factor which results from this procedure of repeated subtraction and averaging does not represent any given tank, but is rather an expected value.

The analysis shows that for emission purposes seals may be divided into two types: liquid-mounted and vapor-mounted. An emission comparison of reduced results between the foam-filled vapor-mounted seal tested during Phase 3 and 3R and the vapor-mounted wipers tested in Phase 1 and 1R, shows that emissions from the foam-filled seal were lower than the Phase 1 wiper but higher than the Phase 1R wiper (Table C-7). On this basis, the results from Phases 1, 1R, 3 and 3R were merged into the general category of vapor-mounted seal.

The analysis shows that emissions from the liquid-mounted seal tested in Phase 2 and 2R are lower than both the average of the merged vapor-mounted seal tests and the individual vapor-mounted seal systems that were actually tested (Table C-8).

Another finding was the presence of the secondary seal reduced emissions whether or not the primary seal was gapped. Emissions reductions obtained by a secondary seal average 47 percent for a liquid-mounted primary seal and 63 percent for a vapor-mounted primary seal.

C.2.2 Deck Seam Losses

The welded IFR tested in Phase 2 and 2R was assumed to have no deck seam emissions. The IFR's tested in Phases 1, 1R, 3 and 3R have bolted deck seams. The seams in the contact deck (3 and 3R) had a different construction than those in the noncontact deck (1 and 1R). However, the

Table C-7. COMPARISON OF WIPER SEALS TO FOAM-FILLED VAPOR-MOUNTED SEALS

Seal gaps (in²/ft diameter)	Seal emissions (lb mole/day) Phase 1 wiper	Foam-filled	Phase 1R wiper
0	0.0566	0.0248	0.0217
1	0.0978	0.0324	—[1]
3	—[1]	0.0402	0.0319

[1] No test available.

Table C-8. COMPARISON OF LIQUID-MOUNTED SEAL TO VAPOR-MOUNTED SEAL

Seal gap (in^2/ft diameter)	Seal emissions (lb mole/day)	
	Liquid-mounted	Vapor-mounted[1]
0	0.0052	0.0217
1	0.0176	—[2]
3	0.030	0.0319

[1] Based on the best performing vapor-mounted seal (Phase 1R wiper).

[2] No test available.

test data show that there is no significant difference in emissions from the seams in the two decks (on a per-foot-of-seam-basis) despite differences in construction and position relative to the stored liquid (Table C-9). It should be noted that Test API 76 was not used in making the comparison. API representatives have stated that due to slight problems in the test, Test API 76 is not comparable with API 76R.[4]

The per-foot-of-seam results that appear in Table C-9 were averaged together and divided by the value of the vapor pressure function to develop the deck seam emission factor K_d. Further minor mathematical procedures are needed to develop K_d as it appears in Chapter 3. These procedures relate seam length to deck diameter.

C.2.3 Effect of Liquid Type on Emissions

Comparisons between previous test programs had indicated that emissions for single component (pure) liquids (e.g., benzene), could be significantly higher than emissions from multicomponent liquids (e.g., gasoline) when normalized for both molecular weight and vapor pressure.[2] Tests performed in the API program show that between the tested liquids (hexane, propane/octane, and octane) there were no significant emissions differences after normalizing for molecular weight and vapor pressure (Table C-10).

C.2.4 The Effect of Vapor Pressure on Emissions

Several emissions tests (from Phase 2 and 2R) were conducted to determine the effect of the product vapor pressure, P, on the emissions rate. This relationship was evaluated during these tests by varying the product vapor pressure in the pilot test tank which had been fitted with a contact-type internal floating roof and a liquid-mounted primary seal. Based on these tests, the emissions are directly related to the vapor pressure function, P*:

$$P^* = \frac{\frac{P}{14.7}}{\left[1 + \left(1 - \frac{P}{14.7}\right)^{0.5}\right]^2}$$

C.2.5 Fitting Emissions

The fitting emission factors are developed by a procedure similar to that used for seal factors. A particular fitting design is analyzed to determine emission points and the results of the bench tests are

Table C-9. BOLTED DECK SEAM EMISSIONS[1]

Test number	Product type	Nominal vapor pressure (psia)	Vapor mole weight (lbm/lbmole)	Deck seams	Total deck seam length (ft)	Emissions at nominal vapor pressure (lbmole/day)	Emissions per foot of deck seam (lbmole/day)
Bolted, Contact IFR							
API 55	C3/nC8	5.00	48.1	Sealed	89	0.0156	
API 56	C3/nC8	5.00	48.2	Unsealed	89	0.0338	0.0002
Bolted, Noncontact IFR							
API 76R	C3/nC8	5.00	46.8	Unsealed	36	0.0433	
API 77	C3/nC8	5.00	47.1	Sealed	36	0.0417	0.00004

[1] Other test conditions:

Primary seal - sealed
Secondary seal - none
Deck fittings - sealed

Table C-10. COMPARISON OF EMISSIONS AS A FUNCTION OF LIQUID TYPE

Test number[1]	Product type	Emissions[2] (lb mole/day)
Phase 2, 2R		
API 50	nC8	0.0510
API 67	nC8	0.0599
API 67A	nC8	0.0932
API 68	nC6	0.0233
API 69	nC6	0.0159
API 71	C3/nC8	0.0247
API 72	C3/nC8	0.040
API 36	C3/nC8	0.0359
Phase 3, 3R		
API 64	nC8	0.103
API 65	nC6	0.0537
API 65R	nC6	0.0905
API 65A	nC6	0.0927
API 60	C3/nC8	0.0574

[1] All tests had identical conditions as follows:

a. 1 in^2/ft. diameter of gap on primary seal.
b. No secondary seal.
c. All roof components unsealed.

[2] Emissions are normalized to 5.0 psia.

added and subtracted to account for each emission source in the design. The individual emission sources are summed, and the resulting sum is made independent of molecular weight and vapor pressure to form the fitting factor.

The test results show that the addition of gaskets and the bolting of covers will reduce emissions from fittings. Also demonstrated is the fact that small fitting design differences can lead to significant differences in emissions.

C.3 REFERENCES

1. Laverman, Royce J. et. al. Testing Program to Measure Hydrocarbon Emissions from a Controlled Internal Floating Roof Tank; (Unpublished), Chicago Bridge and Iron Co. Chicago, Illinois. March 1982. 304 pp.

2. U.S. Environmental Protection Agency. Measurements of Benzene Emissions from a Floating Roof Test Tank. Report No. EPA-450/3-79-020. Research Triangle Park, N.C. June 1979.

3. Letter and attachments from O'Keefe, William, F., American Petroleum Institute, to Wyatt, Susan R., EPA. January 25, 1983.

4. Moody, W.T., TRW, Meeting on September 2, 1982, Durham, N.C., between API, EPA, and TRW.

APPENDIX D

ESTIMATED NATIONWIDE PETROLEUM STORAGE TANK VOC EMISSIONS FOR THE YEARS 1983 AND 1988

D.1 INTRODUCTION

The purpose of this project was to estimate nationwide volatile organic compound (VOC) emissions from petroleum storage tanks for the years 1983 and 1988. Annual VOC emissions from fixed roof, internal floating roof, and external floating roof tanks having capacities greater than 40,000 gallons were estimated. However, the emission estimates do not include VOC emissions from tanks at oil production facilities.

In 1977 Pacific Environmental Services, Inc. (PES) completed for the U.S. Environmental Protection Agency (EPA) a study to evaluate VOC emissions from petroleum storage tanks.[1] The nationwide number of tanks and, subsequently, the annual VOC emissions from these tanks were estimated by first compiling a detailed data base. For approximately 25,000 tank locations throughout the United States, information was collected for each individual tank about the tank construction and the properties of the petroleum liquid stored in the tank. Annual VOC emissions for each tank location were calculated using the emission equations described in the EPA document Compilation of Air Pollutant Emission Factors (AP-42). Results for the calculations were summed for direct addition to the total emission estimates. The results were then averaged to obtain tank emission factors. These factors were used to approximate tank VOC emissions at refinery, terminal, and pipeline facility locations not listed in the compiled tank data base.

The VOC emission estimates for petroleum storage tanks for the years 1983 and 1988 presented in this report represent the results obtained by performing the calculation procedures of the original 1977 PES study using updated emission equations and petroleum industry growth data. The original PES study tank data base was used for the emission estimates. This data base reflects tank construction practices and petroleum liquid storage patterns that prevailed in 1976. The allocated budget for the project was limited and funds were not available for updating the data base to 1983. However, for the purpose of estimating nationwide VOC emissions from petroleum storage tanks, it is reasonable to assume the data base is still representative of the petroleum liquid storage patterns in the United States.

D.2 METHODOLOGY

A detailed description of the calculation procedure used to estimate nationwide VOC emissions from petroleum storage tanks is presented in the EPA document Evaluation of Hydrocarbon Emissions from Petroleum Liquid Storage (EP-450/3-78-012).[1] For this project, the procedure was updated to use the revised American Petroleum Institute (API) tank evaporation loss equations. The VOC emissions from fixed roof and ~~external~~ floating roof tanks were calculated using the equations described in the April 1981, supplement to AP-42.[2] The VOC emissions from internal floating roof tanks were calculated using equations described in the August 1982, draft of the revised API Publication 2519.[3]

Using the revised API evaporation loss equations, VOC emissions were recalculated for the same numbers of petroleum storage tanks estimated by the original PES study. External floating roof tanks were assumed to be equipped with a primary metallic shoe seal only ($K_s = 1.2$, $N = 1.5$). Internal floating roof tanks were assumed to be equipped with "typical fittings." For this study, the total deck fitting loss (TDFL) factor for internal floating roof tanks equipped with typical fittings was obtained from a graph of TDFL factor for a non-welded deck as a function of tank diameter (refer to Figure 1 in Reference 3).

The numbers of tanks constructed since the reference year, 1976, were estimated for the years 1983 and 1988. Projections of new tank construction between 1977 and 1983 were made by extrapolating the number of tanks estimated for each volatility class in the reference year. The methodology is described in Section A.4.1 of the report Evaluation of Hydrocarbon Emissions from Petroleum Liquid Storage. Refining capacity for the year 1983 was determined by summing the total United States refining capacity in January 1982 as reported in the Oil and Gas Journal[4] plus the refinery capacity expansion projects scheduled for completion in 1982 as announced in Hydrocarbon Processing.[5] Because very little specific refinery expansion information is available for years beyond 1984, the number of new tanks expected to be constructed for the years 1984 to 1988 were projected assuming an annual growth rate of 2 percent in the tank population for each volatility class.

The nationwide VOC emissions from petroleum storage tanks for the years 1983 and 1988 were estimated assuming a variety of possible scenarios. The assumptions made for each scenario are described below. Table 1 presents a summary comparison of all six scenarios used for the 1988 VOC emission estimates.

SCENARIO A

1. All tanks built after 1976 to store petroleum products having a vapor pressure greater than 1.5 pisa are assumed to be either external or internal floating roof tanks. All other tanks built after 1976 are assumed to be fixed roof tanks.
2. Distribution of new external and internal floating roof tanks assumed to follow historic pattern shown in reference year data base (90 percent external floating roof tanks, 10 percent internal floating roof tanks).
3. External floating roof tanks are assumed to be equipped with a primary metallic shoe only ($K_s = 1.2$, $N = 1.5$).
4. Internal floating roof tanks are assumed to be equipped with typical fittings.

SCENARIO B

1. All tanks built after 1976 to store petroleum products having a vapor pressure greater than 1.5 psia are assumed to be either external or internal floating roof tanks. All other tanks built after 1976 are assumed to be fixed roof tanks.
2. Distribution of new external and internal floating roof tanks assumed to follow historic pattern shown in reference year data base (90 percent external floating roof tanks, 10 percent internal floating roof tanks).
3. External floating roof tanks are assumed to be equipped with a vapor mounted resilient primary seal with rim mounted secondary seal ($K_s = 0.2$, $N = 2.6$).

Table D-1

ASSUMPTIONS USED FOR PROJECTIONS OF NEW TANK CONSTRUCTION

SCENARIO A

VOLATILITY CLASS	1977 - 1983	1984 - 1988
1 2 3	Fixed	Fixed
4 5 6	10% Internal FR-T 90% External FR-PM	10% Internal FR-T 90% External FR-PM

SCENARIO B

VOLATILITY CLASS	1977 - 1983	1984 - 1988
1 2 3	Fixed	Fixed
4 5 6	10% Internal FR-T 90% External FR-PVS	10% Internal FR-T 90% External FR-PVS

SCENARIO C

VOLATILITY CLASS	1977 - 1983	1984 - 1988
1 2 3	Fixed	Fixed
4 5 6	10% Internal FR-T 90% External FR-PVS	$\leq 3 \times 10^6$ gal Internal FR-WC $>3 \times 10^6$ gal External FR-PMS

Fixed: fixed roof tank
Internal FR-T: internal floating roof tank with typical fittings.
Internal FR-WC: internal floating roof tank with well-controlled fittings.
External FR-PM: external floating roof tank with primary metallic shoe seal.
External FR-PMS: external floating roof tank with primary metallic shoe seal plus secondary seal.
External FR-PVS: external floating roof tank with primary vapor plus secondary seal.

Table D-1

ASSUMPTIONS USED FOR PROJECTIONS OF NEW TANK CONSTRUCTION

(concluded)

SCENARIO D

VOLATILITY CLASS	1977 - 1983	1984 - 1988
1	Fixed	Fixed
2		
3	10% Internal FR-T 90% External FR-PVS	$\leq 3 \times 10^6$ gal Internal FR-WC $> 3 \times 10^6$ gal External FR-PMS
4		
5		
6		

SCENARIO E

VOLATILITY CLASS	1977 - 1983	1984 - 1988
1	Fixed	Fixed
2		
3		
4	10% Internal FR-T 90% External FR-PVS	10% Internal FR-WC 90% External FR-PMS
5		
6		

SCENARIO F

VOLATILITY CLASS	1977 - 1983	1984 - 1988
1	Fixed	Fixed
2		
3	10% Internal FR-T 90% External FR-PVS	10% Internal FR-WC 90% External FR-PMS
4		
5		
6		

Fixed: fixed roof tank.
Internal FR-T: internal floating roof tank with typical fittings.
Internal FR-WC: internal floating roof tank with well-controlled fittings.
External FR-PM: external floating roof tank with primary metallic shoe seal.
External FR-PMS: external floating roof tank with primary metallic shoe seal plus secondary seal.
External FR-PVS: external floating roof tank with primary vapor plus secondary seal.

4. Internal floating roof tanks are assumed to be equipped with typical fittings.

SCENARIO C

1. All tanks built between 1977 and 1983 follow the Scenario B assumptions. All tanks built between 1984 and 1988 follow assumptions 2 through 5.

2. All tanks built after 1983 to store petroleum products having a vapor pressure greater than 1.5 psia are assumed to be either external or internal floating roof tanks. All other tanks built after 1983 are assumed to be fixed roof tanks.

3. Distribution of new external and internal floating roof tanks assumed to be:

   a. Tanks having a capacity greater than 3 million gallons are external floating roof tanks.

   b. Tanks having a capacity less than or equal to 3 million gallons are internal floating roof tanks.

4. External floating roof tanks are assumed to be equipped with a primary metallic shoe seal with rim mounted secondary seal ($K_s = 0.2$, $N = 1.0$).

5. Internal floating roof tanks are assumed to be equipped with well-controlled fittings. A well-controlled internal floating roof tank was defined for this study to have:

   a. Access hatch

      Bolted cover, gasketed ($K_f = 1.6$)

   b. Automatic gauge floatwell

      Bolted cover, gasketed ($K_f = 5.1$)

   c. Column well

      Pipe column-flexible fabric sleeve seal ($K_f = 10$)

   d. Ladder well

      Sliding cover, gasketed ($K_f = 56$)

   e. Roof leg

      Adjustable ($K_f = 7.9$)

f. Sample pipe

Sample well-slit fabric seal ($K_f = 12$)

g. Stub drain ($K_f = 1.2$)

h. Vacuum breaker

Weighted mechanical actuation, gasketed ($K_f = 0.7$)

SCENARIO D

1. All tanks built between 1977 and 1983 follow the Scenario B assumptions. All tanks built between 1984 and 1988 follow assumptions 2 through 5.

2. All tanks built after 1983 to store petroleum products having a vapor pressure greater than 1.0 psia are assumed to be either external or internal floating roof tanks. All other tanks built after 1983 are assumed to be fixed roof tanks.

3. Distribution of new external and internal floating roof tanks assumed to be:

    a. Tanks having a capacity greater than 3 million gallons are external floating roof tanks.

    b. Tanks having a capacity less than or equal to 3 million gallons are internal floating roof tanks.

4. External floating roof tanks are assumed to be eqiupped with a primary metallic shoe seal with rim mounted secondary seal ($K_s = 0.2$, $N = 1.0$).

5. Internal floating roof tanks are assumed to be equipped with well-controlled fittings. (See Scenario C, assumption 5).

SCENARIO E

1. All tanks built between 1977 and 1983 follow the Scenario B assumptions. All tanks built between 1984 and 1988 follow assumptions 2 through 5.

2. All tanks built after 1983 to store petroleum products having a vapor pressure greater than 1.0 psia are assumed to be either external or internal floating roof tanks. All other tanks built after 1983 are assumed to be fixed roof tanks.

3. Distribution of new external and internal floating roof tanks assumed to follow historic pattern shown in reference year data base (90 percent external floating roof tanks, 10 percent internal floating roof tanks).

4. External floating roof tanks are assumed to be eqiupped with a primary metallic shoe seal with rim mounted secondary seal (K_s = 0.2, N = 1.0).

5. Internal floating roof tanks are assumed to be equipped with well-controlled fittings. (See Scenario C, assumption 5).

SCENARIO F

1. All tanks built between 1977 and 1983 follow the Scenario B assumptions. All tanks built between 1984 and 1988 follow assumptions 2 through 5.

2. All tanks built after 1983 to store petroleum products having a vapor pressure greater than 1.0 psia are assumed to be either external or internal floating roof tanks. All other tanks built after 1983 are assumed to be fixed roof tanks.

3. Distribution of new external and internal floating roof tanks assumed to follow historic pattern shown in reference year data base (90 percent external floating roof tanks, 10 percent internal floating roof tanks).

4. External floating roof tanks are assumed to be eqiupped with a primary metallic shoe seal with rim mounted secondary seal (K_s = 0.2, N = 1.0).

5. Internal floating roof tanks are assumed to be equipped with well-controlled fittings. (See Scenario C, assumption 5).

D.3 RESULTS

Estimated total nationwide annual VOC emissions from petroleum storage tanks are presented in the following tables.

Table 2 - Reference year
Table 3 - 1983 Scenario A
Table 4 - 1983 Scenario B
Table 5 - 1988 Scenario A
Table 6 - 1988 Scenario B
Table 7 - 1988 Scenario C
Table 8 - 1988 Scenario D
Table 9 - 1988 Scenario E
Table 10 - 1988 Scenario F

Estimated total nationwide numbers of petroleum storage tanks are presented in the following tables.

Table 11 - Reference year
Table 12 - 1983 Scenarios A and B
Table 13 - 1988 Scenarios A, B, and E
Table 14 - 1988 Scenario C
Table 15 - 1988 Scenario D
Table 16 - 1988 Scenario F

Table D-2
ESTIMATED TOTAL ANNUAL VOC EMISSIONS FROM PETROLEUM STORAGE TANKS[a]
REFERENCE YEAR

Volatility Range (psia)	Petroleum Storage Tank VOC Emissions (tons per year)			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤ 0.5	20,400	30	830	21,260
0.5 to 1.0	11,700	40	620	12,360
1.0 to 1.5	75,600	130	2,100	77,830
1.5 to 5.0	313,400	3,400	55,500	372,300
5.0 to 9.1	106,600	2,400	58,000	167,000
9.1 to 11.1	15,900	330	9,500	25,730
TOTAL	543,600	6,330	126,550	676,480

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-3

ESTIMATED TOTAL ANNUAL VOC EMISSIONS FROM PETROLEUM STORAGE TANKS[a]
1983 - SCENARIO A

Volatility Range (psia)	Petroleum Storage Tank VOC Emissions (tons per year)			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤0.5	22,800	30	830	23,660
0.5 to 1.0	13,400	40	620	14,060
1.0 to 1.5	87,000	130	2,100	89,230
1.5 to 5.0	313,400	4,100	66,600	384,100
5.0 to 9.1	106,600	2,800	67,000	176,400
9.1 to 11.1	15,900	390	10,800	27,090
TOTAL	559,100	7,490	147,950	714,540

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-4
ESTIMATED TOTAL ANNUAL VOC EMISSIONS FROM PETROLEUM STORAGE TANKS[a]
1983 - SCENARIO B

Volatility Range (psia)	Petroleum Storage Tank VOC Emissions (tons per year)			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤0.5	22,800	30	830	23,660
0.5 to 1.0	13,400	40	620	14,060
1.0 to 1.5	87,000	130	2,100	89,230
1.5 to 5.0	313,400	4,100	76,000	393,500
5.0 to 9.1	106,600	2,800	77,200	186,600
9.1 to 11.1	15,900	390	11,900	28,190
TOTAL	559,100	7,490	168,650	736,240

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-5

ESTIMATED TOTAL ANNUAL VOC EMISSIONS FROM PETROLEUM STORAGE TANKS[a]

1988 - SCENARIO A

Volatility Range (psia)	Petroleum Storage Tank VOC Emissions (tons per year)			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤ 0.5	25,300	30	830	26,160
0.5 to 1.0	15,300	40	620	15,960
1.0 to 1.5	99,100	130	2,100	101,330
1.5 to 5.0	313,400	4,800	78,300	396,500
5.0 to 9.1	106,600	3,200	76,300	186,100
9.1 to 11.1	15,900	440	12,200	28,540
TOTAL	575,600	8,640	170,350	754,590

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-6

ESTIMATED TOTAL ANNUAL VOC EMISSIONS FROM PETROLEUM STORAGE TANKS[a]

1988 - SCENARIO B

Volatility Range (psia)	Petroleum Storage Tank VOC Emissions (tons per year)			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤0.5	25,300	30	830	26,160
0.5 to 1.0	15,300	40	620	15,960
1.0 to 1.5	99,100	130	2,100	101,330
1.5 to 5.0	313,400	4,800	97,600	415,800
5.0 to 9.1	106,600	3,200	97,100	206,900
9.1 to 11.1	15,900	440	14,500	30,840
TOTAL	575,600	8,640	212,750	796,990

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-7

ESTIMATED TOTAL ANNUAL VOC EMISSIONS FROM PETROLEUM STORAGE TANKS[a] 1988 - SCENARIO C

Volatility Range (psia)	Petroleum Storage Tank VOC Emissions (tons per year)			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤0.5	25,300	30	830	26,160
0.5 to 1.0	15,300	40	620	15,960
1.0 to 1.5	99,100	130	2,100	101,330
1.5 to 5.0	313,400	5,300	76,900	395,600
5.0 to 9.1	106,600	3,300	77,700	187,600
9.1 to 11.1	15,900	450	11,900	28,250
TOTAL	575,600	9,250	170,050	754,900

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-8
ESTIMATED TOTAL ANNUAL VOC EMISSIONS FROM PETROLEUM STORAGE TANKS[a]
1988 - SCENARIO D

Volatility Range (psia)	Petroleum Storage Tank VOC Emissions (tons per year)			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤ 0.5	25,300	30	830	26,160
0.5 to 1.0	15,300	40	620	15,960
1.0 to 1.5	87,000	180	2,200	89,380
1.5 to 5.0	313,400	5,300	76,900	395,600
5.0 to 9.1	106,600	3,300	77,700	187,600
9.1 to 11.1	15,900	450	11,900	28,250
TOTAL	563,500	9,300	170,150	742,950

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-9

ESTIMATED TOTAL ANNUAL VOC EMISSIONS FROM PETROLEUM STORAGE TANKS[a]
1988 - SCENARIO E

Volatility Range (psia)	Petroleum Storage Tank VOC Emissions (tons per year)			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤0.5	25,300	30	830	26,160
0.5 to 1.0	15,300	40	620	15,960
1.0 to 1.5	99,100	130	2,100	101,330
1.5 to 5.0	313,400	4,200	78,800	396,400
5.0 to 9.1	106,600	2,900	78,500	188,000
9.1 to 11.1	15,900	400	12,000	28,300
TOTAL	575,600	7,700	172,850	756,150

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-10
ESTIMATED TOTAL ANNUAL VOC EMISSIONS FROM PETROLEUM STORAGE TANKS[a]
1988 - SCENARIO F

Volatility Range (psia)	Petroleum Storage Tank VOC Emissions (tons per year)			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤0.5	25,300	30	830	26,160
0.5 to 1.0	15,300	40	620	15,960
1.0 to 1.5	87,000	140	2,300	89,440
1.5 to 5.0	313,400	4,200	78,800	396,400
5.0 to 9.1	106,600	2,900	78,500	188,000
9.1 to 11.1	15,900	400	12,000	28,300
TOTAL	563,500	7,710	173,050	744,260

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-11
ESTIMATED TOTAL NUMBER OF PETROLEUM STORAGE TANKS[a]
REFERENCE YEAR

Volatility Range (psia)	Number of Petroleum Storage Tanks			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤0.5	15,420	230	1,600	17,250
0.5 to 1.0	790	40	520	1,350
1.0 to 1.5	2,600	90	660	3,350
1.5 to 5.0	5,840	730	6,360	12,930
5.0 to 9.1	1,400	270	3,090	4,760
9.1 to 11.1	50	20	190	260
TOTAL	26,100	1,380	12,420	39,900

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-12
ESTIMATED TOTAL NUMBER OF PETROLEUM STORAGE TANKS[a]
1983 SCENARIO A AND B

Volatility Range (psia)	Number of Petroleum Storage Tanks			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤0.5	17,300	230	1,600	19,130
0.5 to 1.0	910	40	520	1,470
1.0 to 1.5	3,000	90	660	3,750
1.5 to 5.0	5,840	880	7,640	14,360
5.0 to 9.1	1,400	320	3,570	5,290
9.1 to 11.1	50	30	220	300
TOTAL	28,500	1,590	14,210	44,300

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-13

ESTIMATED TOTAL NUMBER OF PETROLEUM STORAGE TANKS[a]

1988 SCENARIOS A, B, AND E

Volatility Range (psia)	Number of Petroleum Storage Tanks			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤0.5	19,230	230	1,600	21,060
0.5 to 1.0	1,310	40	520	1,870
1.0 to 1.5	3,130	90	660	3,880
1.5 to 5.0	5,840	1,030	8,990	15,860
5.0 to 9.1	1,400	360	4,060	5,820
9.1 to 11.1	50	40	240	330
TOTAL	30,960	1,790	16,070	48,820

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-14
ESTIMATED TOTAL NUMBER OF PETROLEUM STORAGE TANKS[a]
1988 SCEARNIO C

Volatility Range (psia)	Number of Petroleum Storage Tanks			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤ 0.5	19,230	230	1,600	21,060
0.5 to 1.0	1,310	40	520	1,870
1.0 to 1.5	3,130	90	660	3,880
1.5 to 5.0	5,840	1,940	8,080	15,860
5.0 to 9.1	1,400	670	3,750	5,820
9.1 to 11.1	50	50	230	330
TOTAL	30,960	3,020	14,840	48,820

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-15
ESTIMATED TOTAL NUMBER OF PETROLEUM STORAGE TANKS[a]
1988 SCEARNIO D

Volatility Range (psia)	Number of Petroleum Storage Tanks			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤0.5	19,230	230	1,600	21,060
0.5 to 1.0	1,310	40	520	1,870
1.0 to 1.5	3,000	200	680	3,880
1.5 to 5.0	5,840	1,940	8,080	15,860
5.0 to 9.1	1,400	670	3,750	5,820
9.1 to 11.1	50	50	230	330
TOTAL	30,830	3,130	14,860	48,820

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

Table D-16
ESTIMATED TOTAL NUMBER OF PETROLEUM STORAGE TANKS[a]
1988 SCEARNIO F

Volatility Range (psia)	Number of Petroleum Storage Tanks			
	Fixed Roof	Internal Floating Roof	External Floating Roof	Total
≤0.5	19,230	230	1,600	21,060
0.5 to 1.0	1,310	40	520	1,870
1.0 to 1.5	3,000	100	780	3,880
1.5 to 5.0	5,840	1,030	8,990	15,860
5.0 to 9.1	1,400	360	4,060	5,820
9.1 to 11.1	50	40	240	330
TOTAL	30,830	1,800	16,190	48,820

[a] Storage tanks having capacities greater than 40,000 gallons and not including tanks at crude oil production facilities.

D.4 REFERENCES

1. Peterson, P., et al., Evaluation of Hydrocarbon Emissions from Petroleum Liquid Storage, EPA-450/3-78-012, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, March 1978.

2. "Storage of Petroleum Liquids," Compilation of Air Pollutant Emission Factors, Supplement No. 9, AP-42, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1981.

3. Evaporation Loss from Internal Floating - Roof Tanks, API Publication 2519, 3rd edition, American Petroleum Institute, Washington, D.C., preliminary draft, August 1982.

4. Cantrell, A., "Annual Refining Survey," Oil and Gas Journal, March 22, 1982, p. 130.

5. "HPI Construction Boxscore," Hydrocarbon Processing, Section 2, October 1982, p. 3 to p. 15.